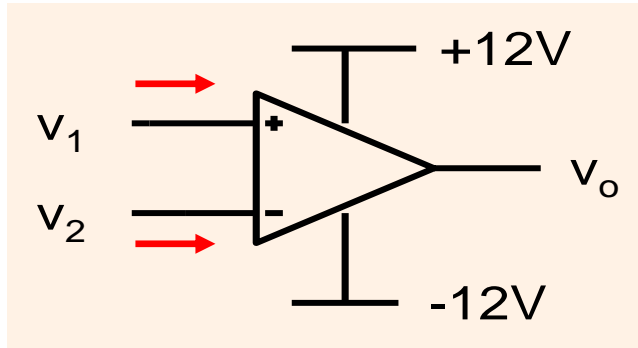


# ESC201T : Introduction to Electronics

## Lecture 30: Operational Amplifier Circuits-2

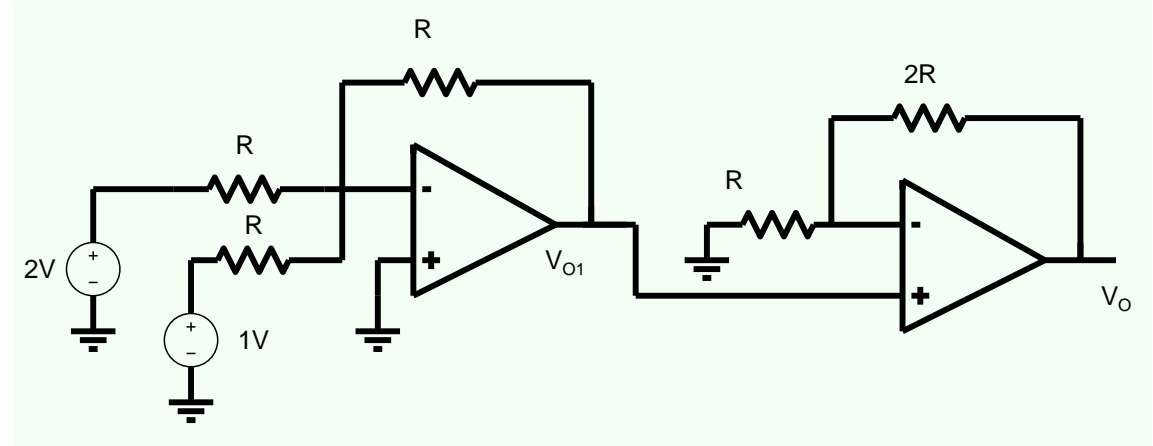
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# Important properties for analyzing ideal opamp circuits under negative feedback



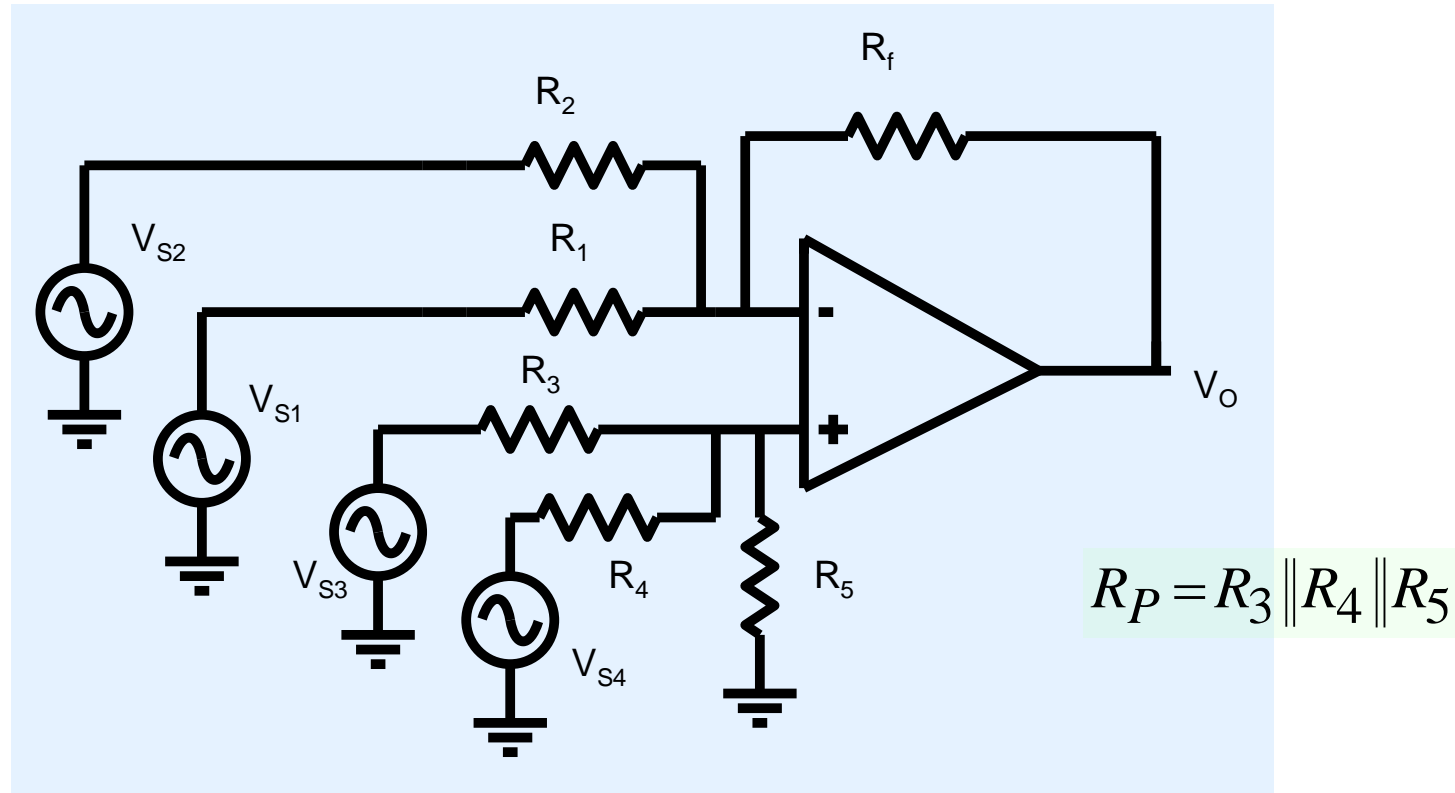
1.  $v_1 = v_2$

2.  $i_1 = i_2 = 0$



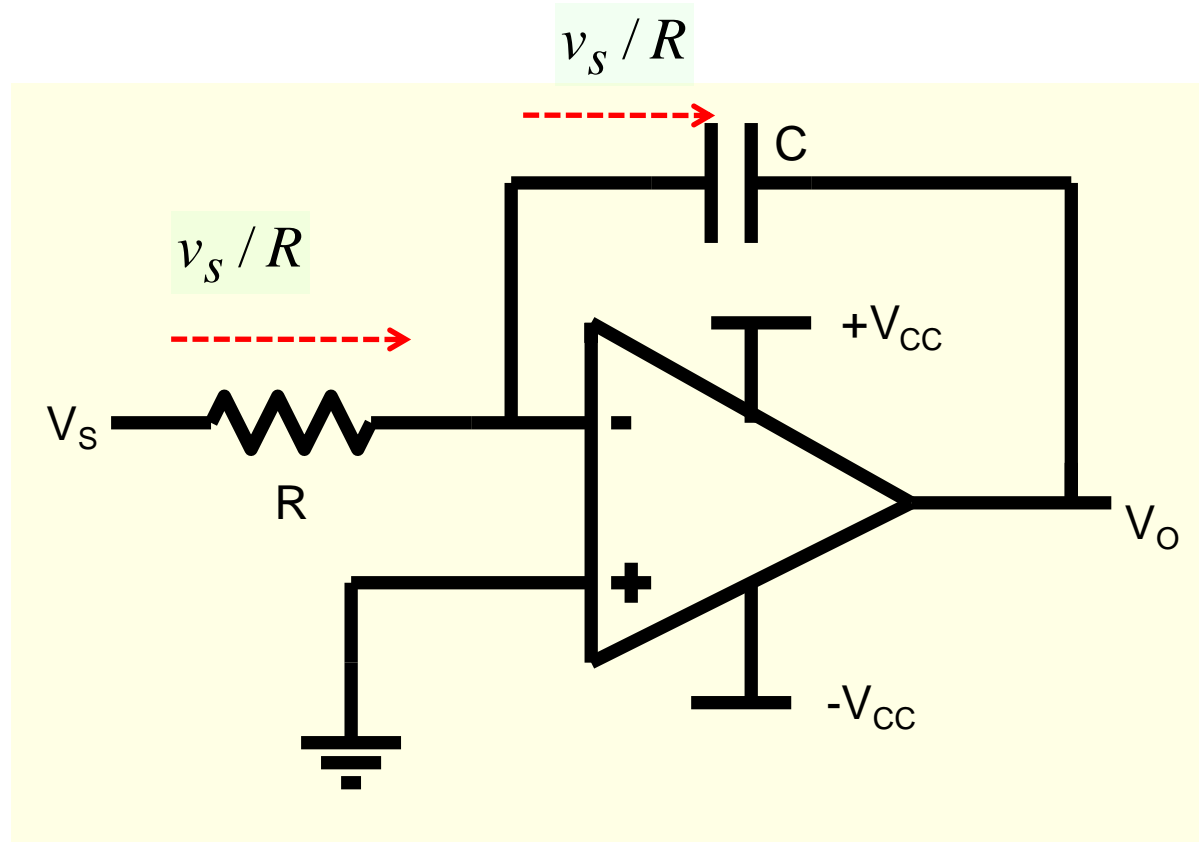
One stage does not load the preceding stage due to very small output impedance of the opamp

# Adder/Subtractor



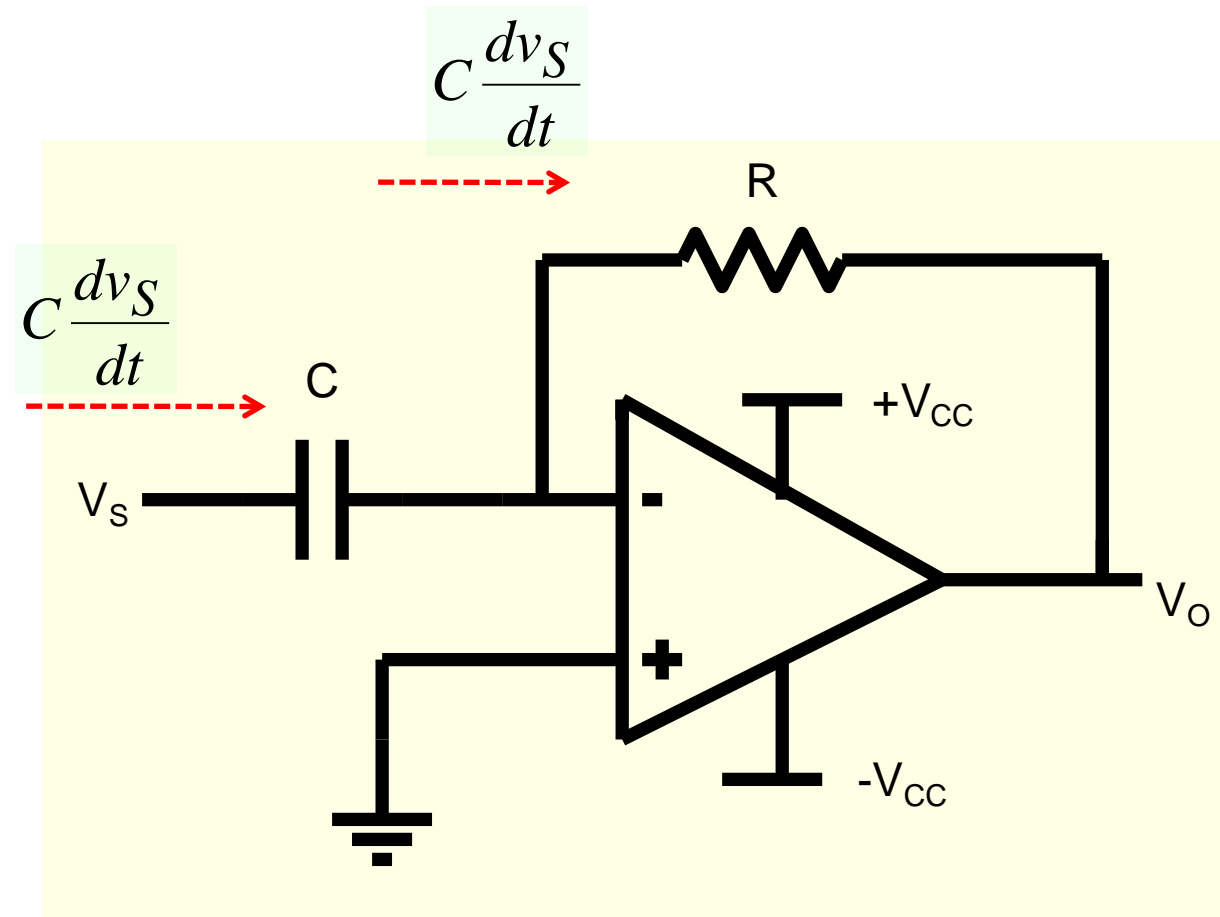
$$v_o = -\left(\frac{R_f}{R_1}\right)v_{s1} + -\left(\frac{R_f}{R_2}\right)v_{s2} + v_{s3} \frac{R_P}{R_3} \times \left(1 + \frac{R_f}{R_1 \parallel R_2}\right) + v_{s4} \frac{R_P}{R_4} \times \left(1 + \frac{R_f}{R_1 \parallel R_2}\right)$$

# Integrator



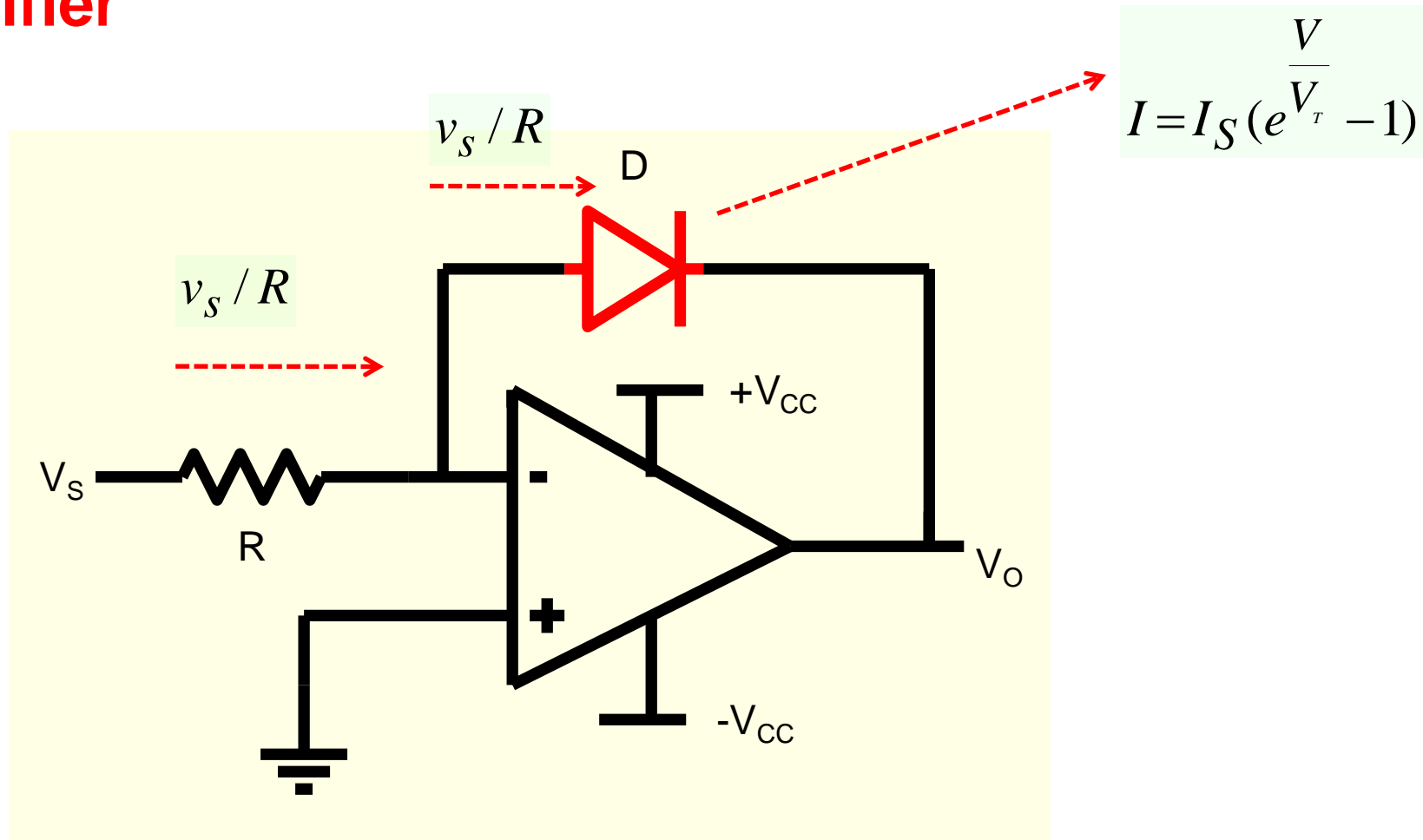
$$\frac{V_s}{R} = -C \frac{dV_o}{dt} \Rightarrow V_o(t) = -\frac{1}{RC} \int V_s dt$$

# Differentiator



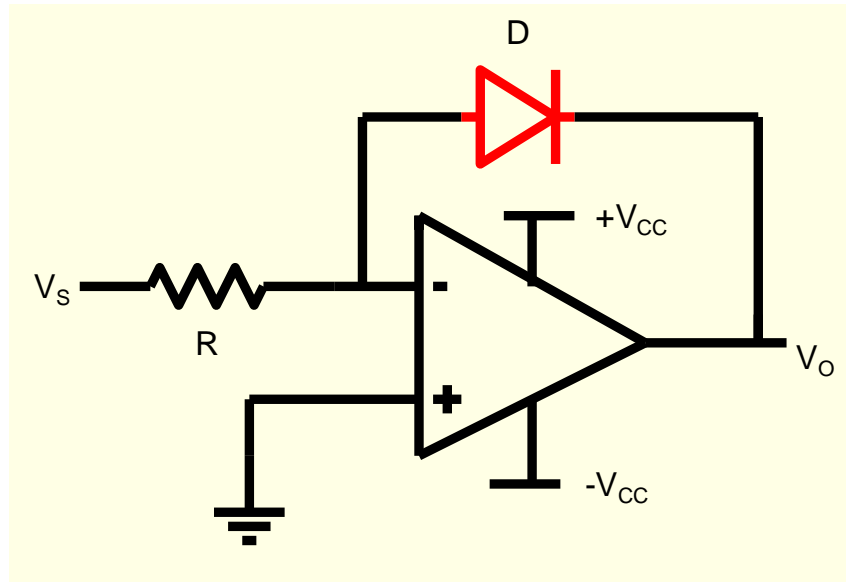
$$-\frac{V_o}{R} = C \frac{dV_s}{dt} \Rightarrow V_o(t) = -RC \frac{dV_s}{dt}$$

# Log Amplifier



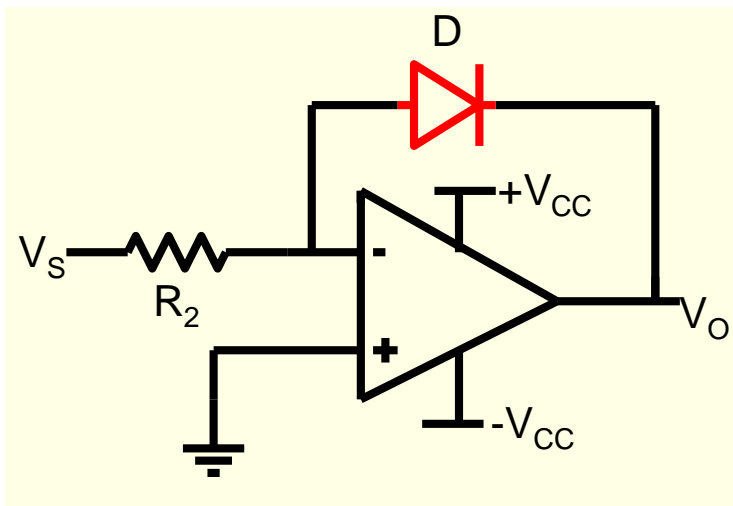
$$\frac{V_S}{R} = I_S (e^{\frac{V_O}{V_T}} - 1) \Rightarrow -V_O = V_T \times \ln\left(1 + \frac{V_S}{RI_S}\right) \cong V_T \times \ln\left(\frac{V_S}{RI_S}\right)$$

# Temperature Sensor ?

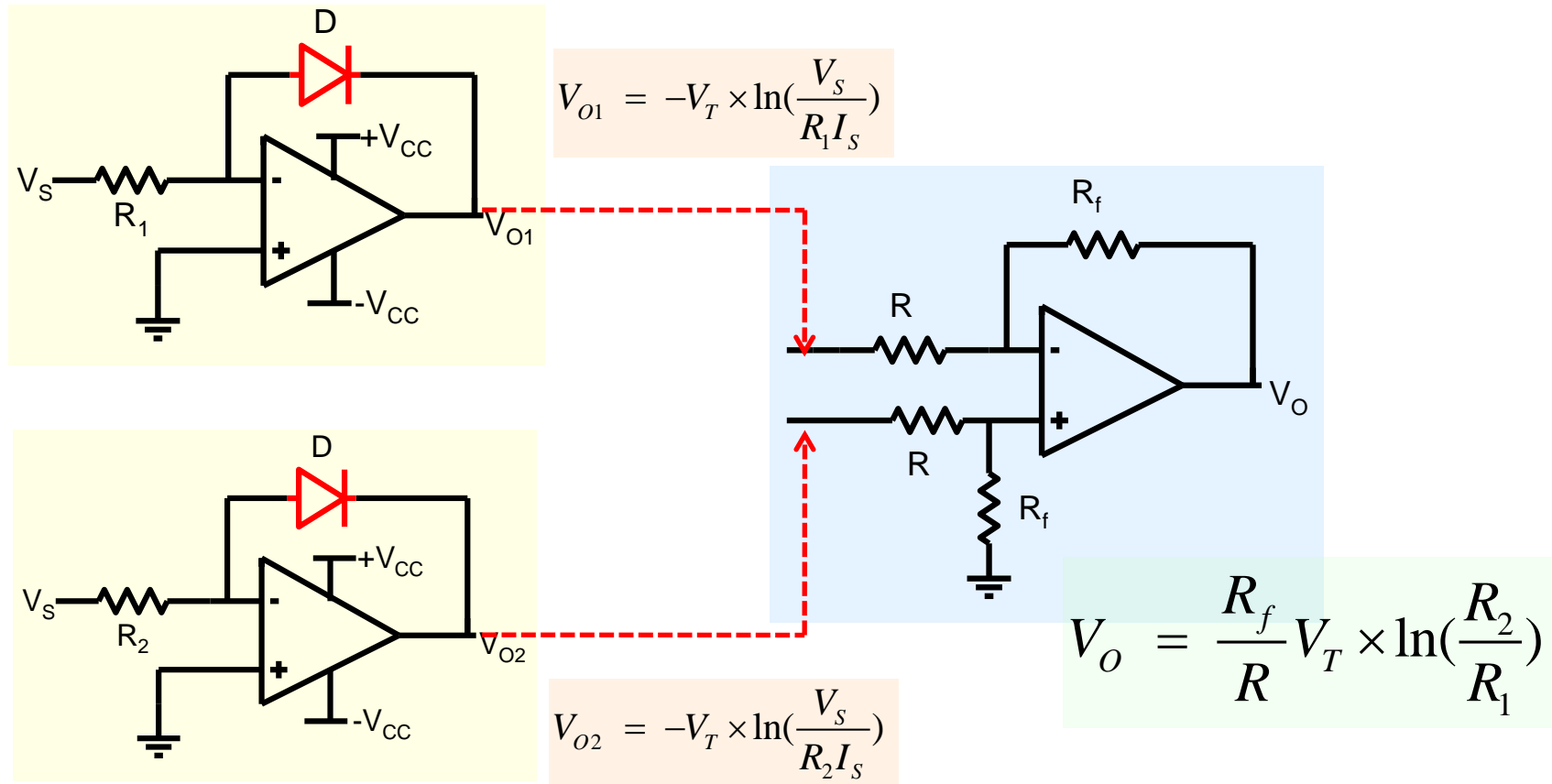


$$V_O = -V_T \times \ln\left(\frac{V_S}{RI_S}\right); V_T = \frac{k_B T}{q}$$

But  $I_S$  is a function of temperature as well.



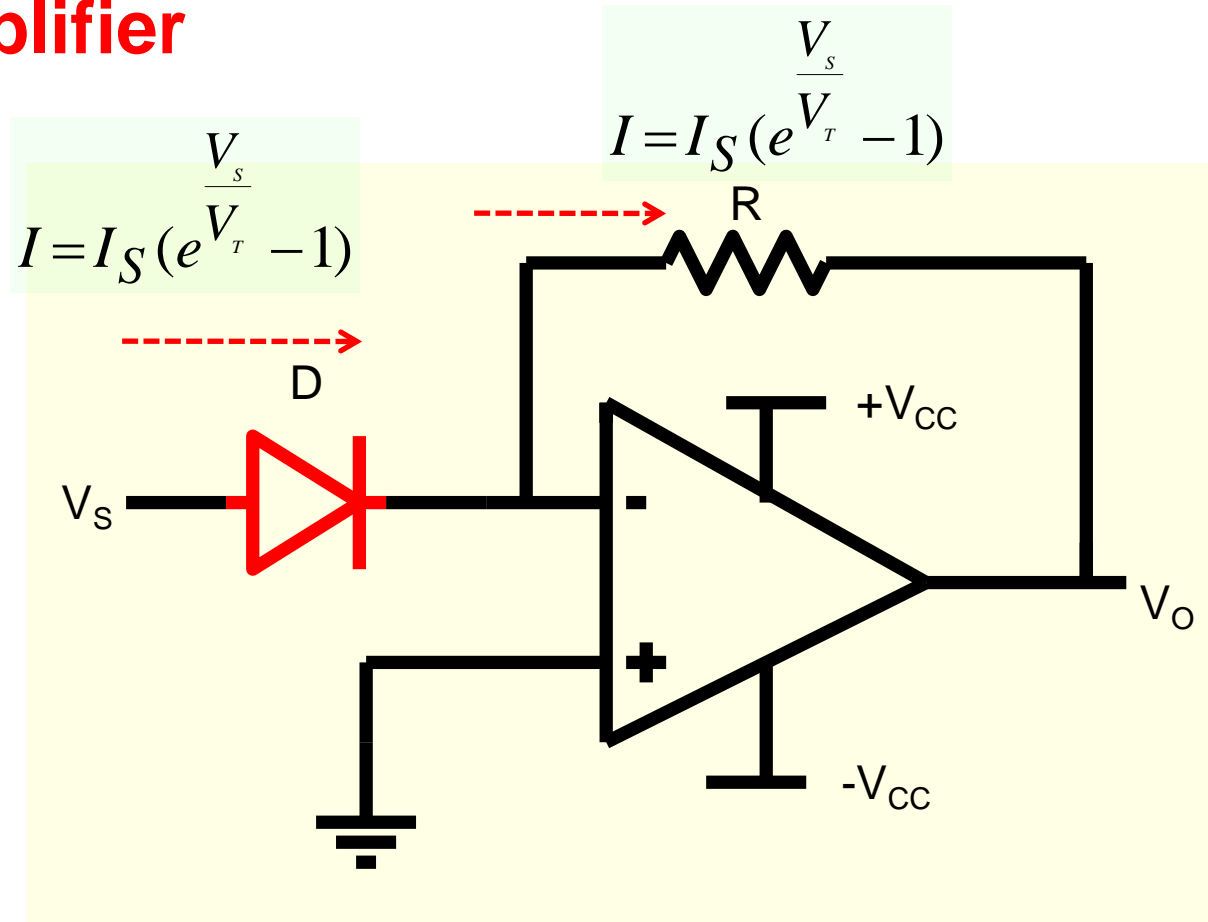
$$V_O = -V_T \times \ln\left(\frac{V_S}{R_2 I_S}\right)$$



Output voltage is directly proportional to temperature

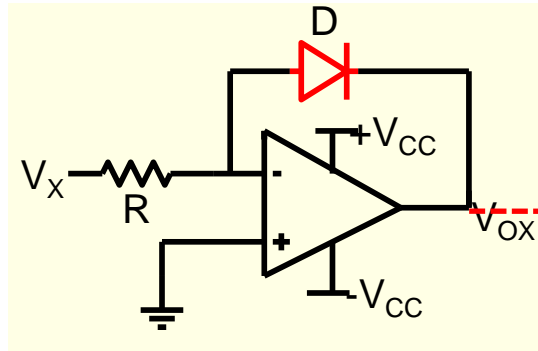


# AntiLog Amplifier



$$-\frac{V_o}{R} = I_S (e^{\frac{V_s}{V_T}} - 1) \Rightarrow V_o = -RI_S (e^{\frac{V_s}{V_T}} - 1) \cong -RI_S \times e^{\frac{V_s}{V_T}}$$

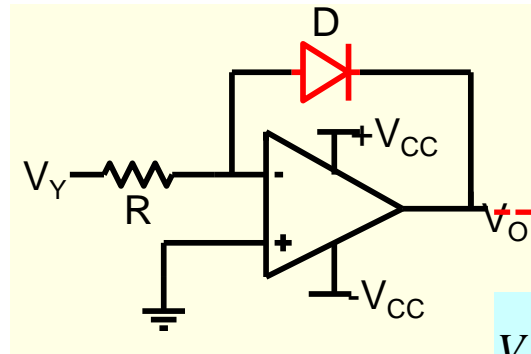
# Multiplier



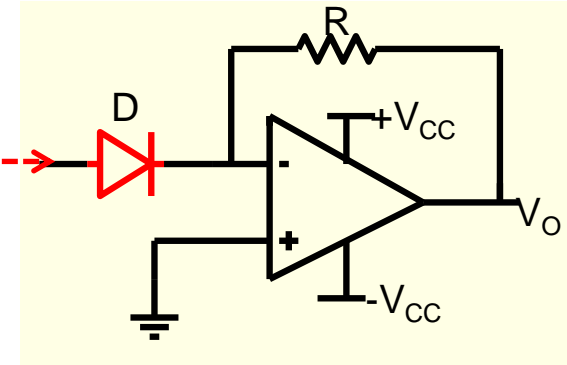
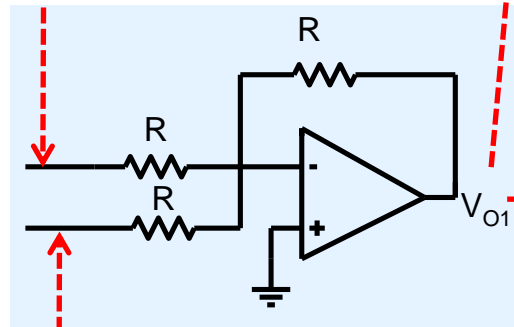
$$V_{OX} = -V_T \times \ln\left(\frac{V_X}{RI_S}\right)$$

$$V_{O1} = V_T \times \left(\ln\left(\frac{V_X}{RI_S}\right) + \ln\left(\frac{V_Y}{RI_S}\right)\right)$$

$$V_{O1} = V_T \times \ln\left(\frac{V_X V_Y}{R^2 I_S^2}\right)$$



$$V_{OY} = -V_T \times \ln\left(\frac{V_Y}{RI_S}\right)$$

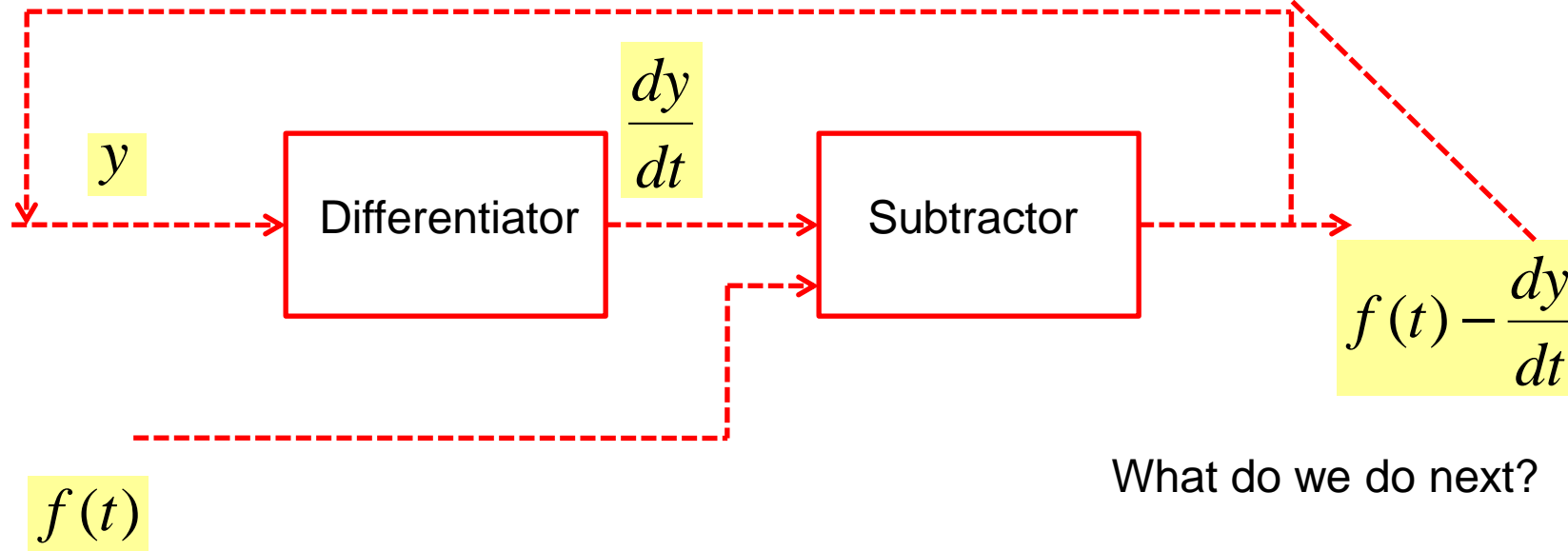


$$V_O \cong -RI_S \times e^{\frac{V_{O1}}{V_T}} = -\frac{V_X V_Y}{RI_S}$$

# Solving Differential Equations?

$$\frac{dy}{dt} + y = f(t)$$

$$y = f(t) - \frac{dy}{dt}$$



What do we do next?

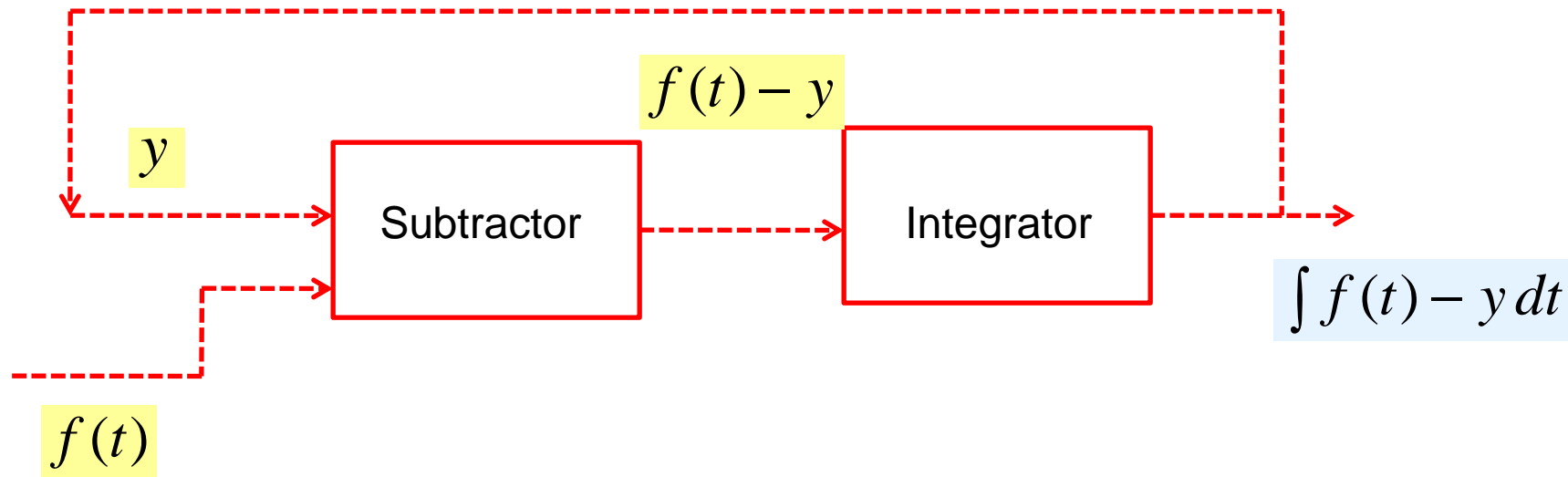
Where do we get  $y$  from?

Integrators are preferred over Differentiators because they are less sensitive to noise

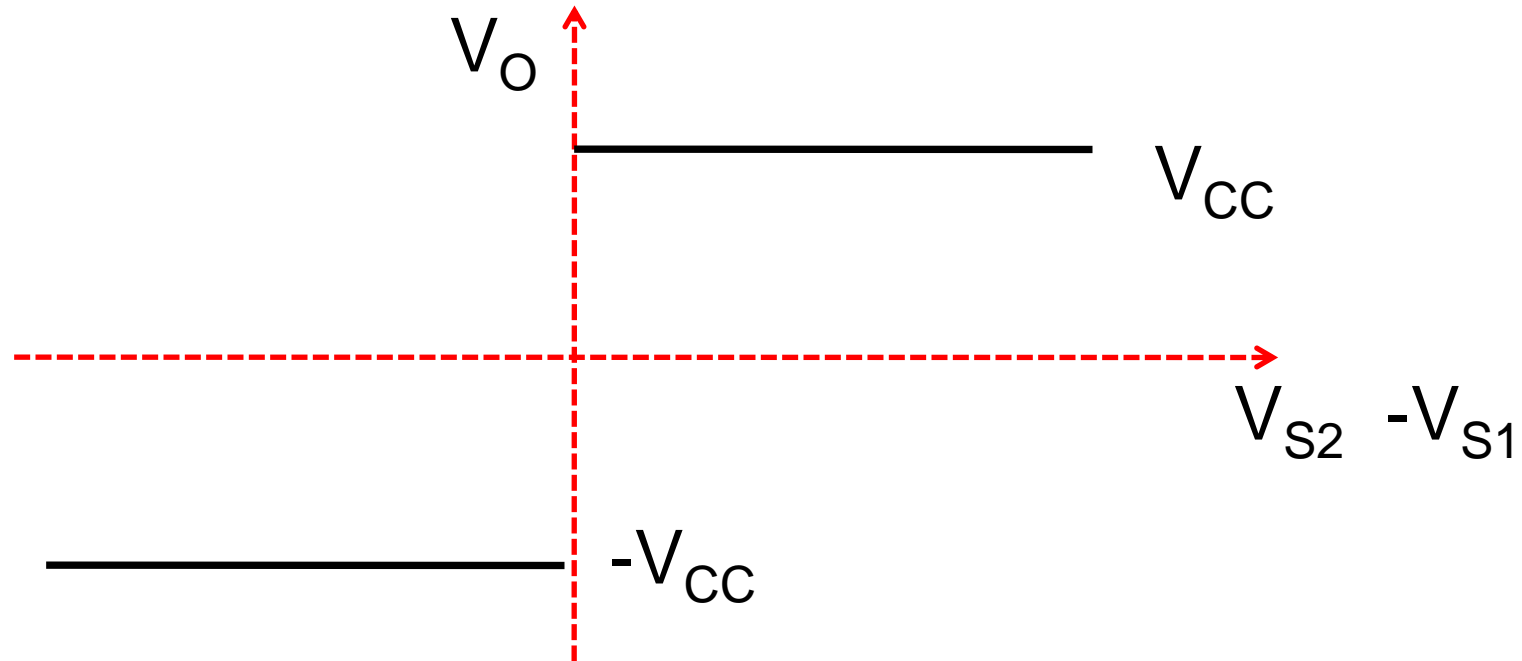
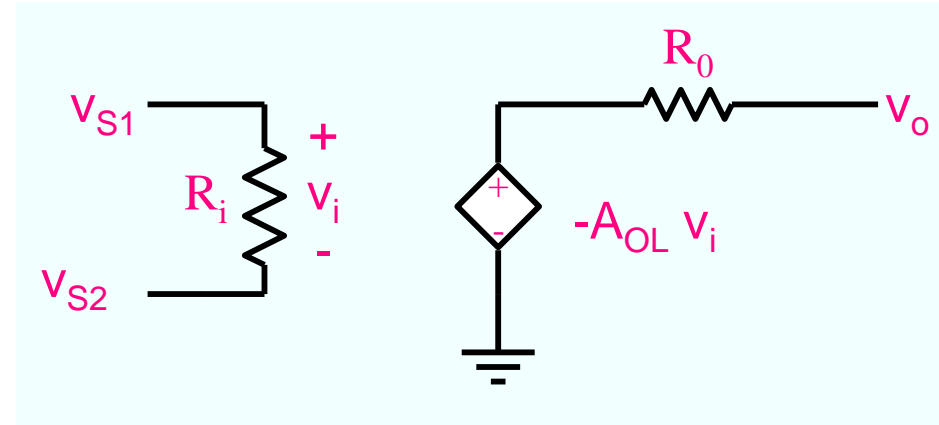
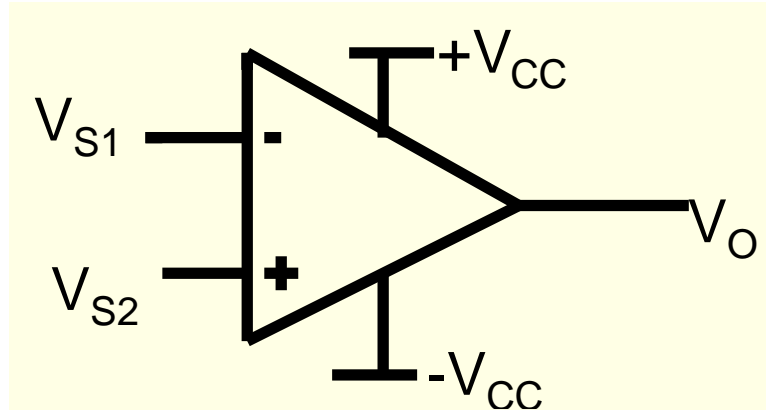
$$\frac{dy}{dt} + y = f(t)$$

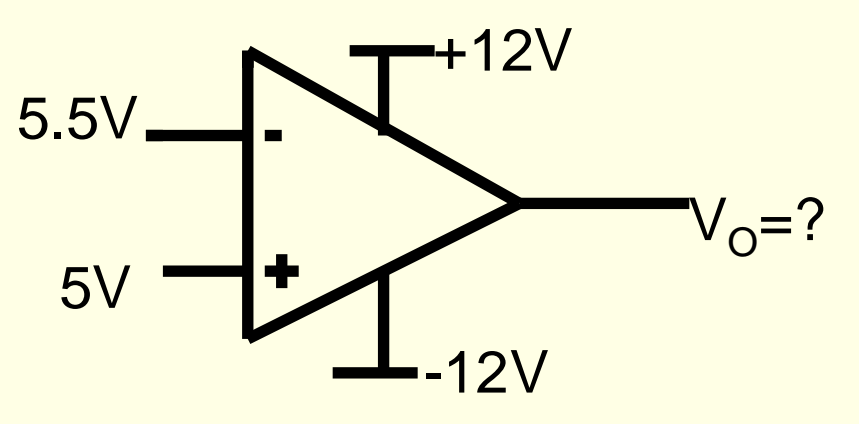
$$\frac{dy}{dt} = f(t) - y \Rightarrow$$

$$y = \int f(t) - y dt$$

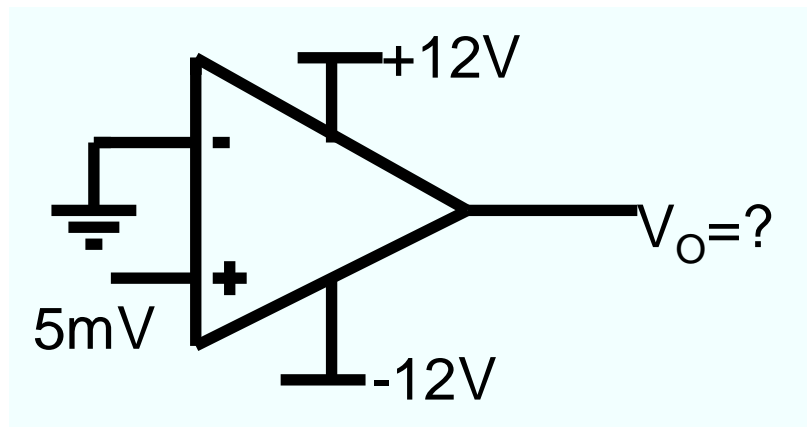


# Comparator: Opamp under open Loop condition





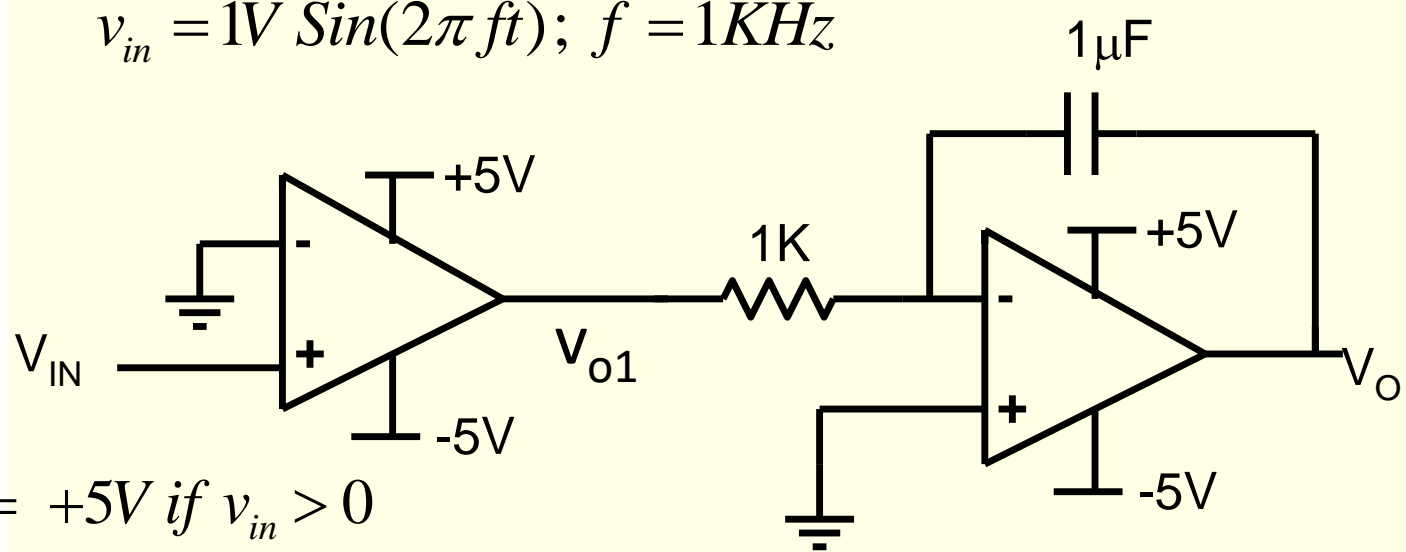
~ -12V



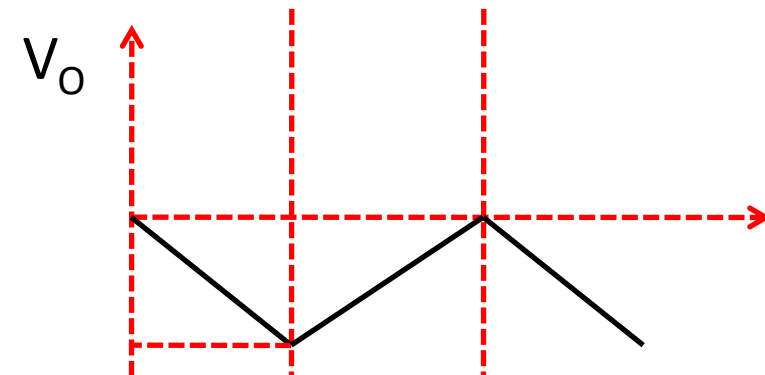
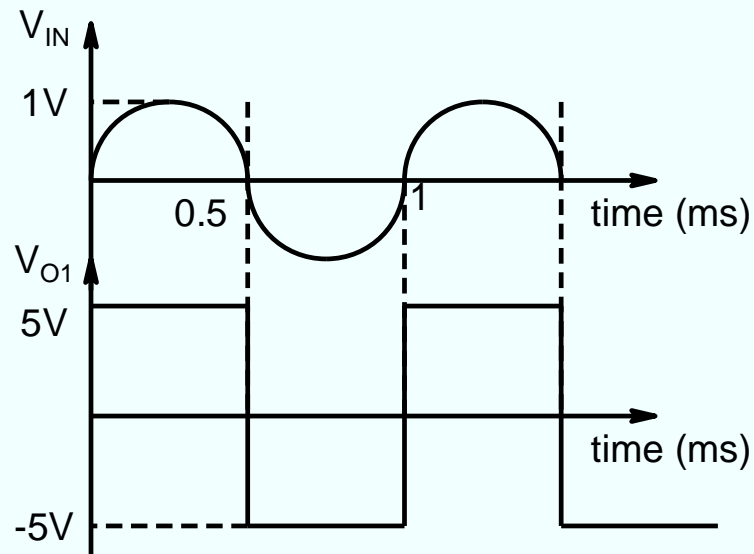
~ +12V

## Example

$$v_{in} = 1V \sin(2\pi ft); f = 1KHz$$



$$V_{O1} = +5V \text{ if } v_{in} > 0$$
$$= -5V \text{ if } v_{in} < 0$$





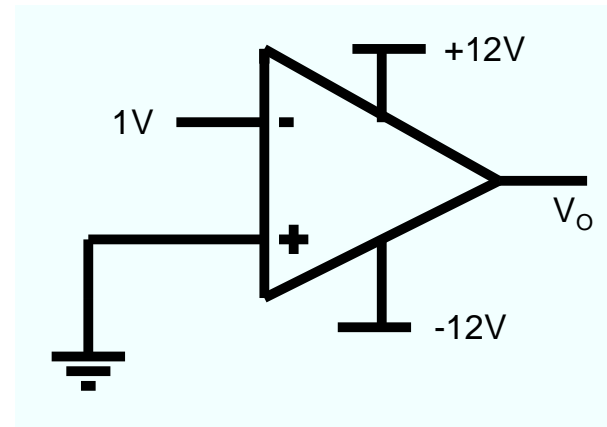
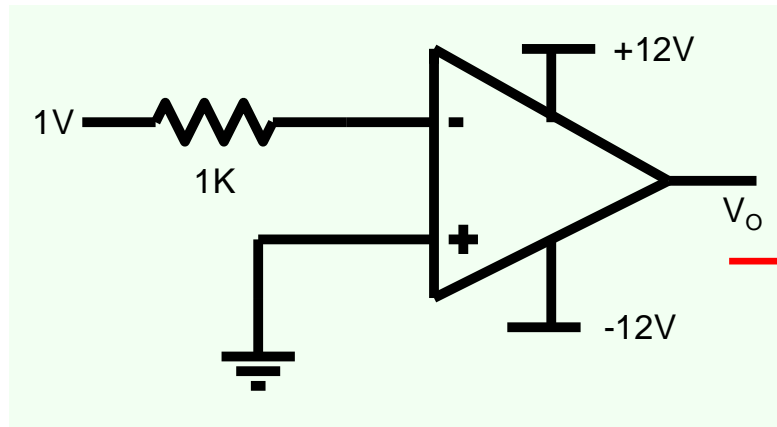
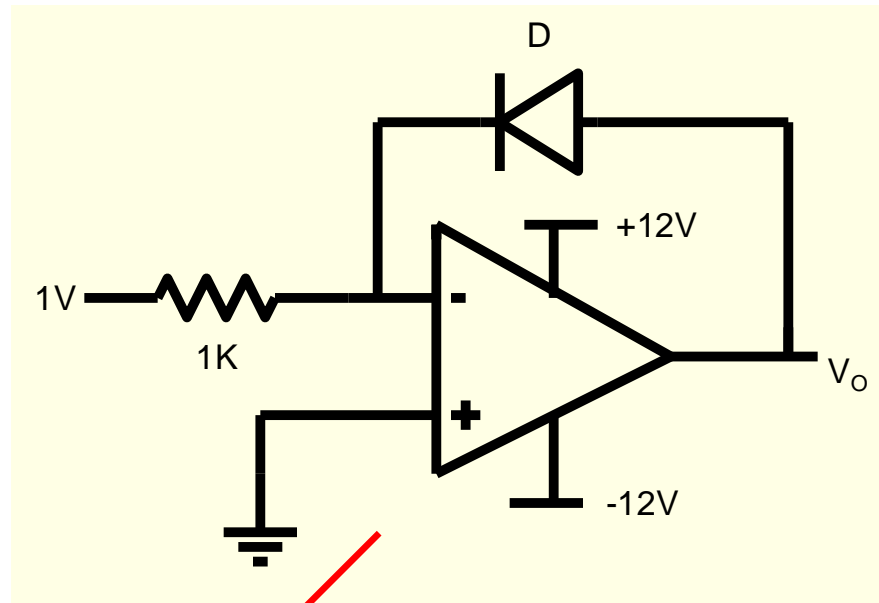






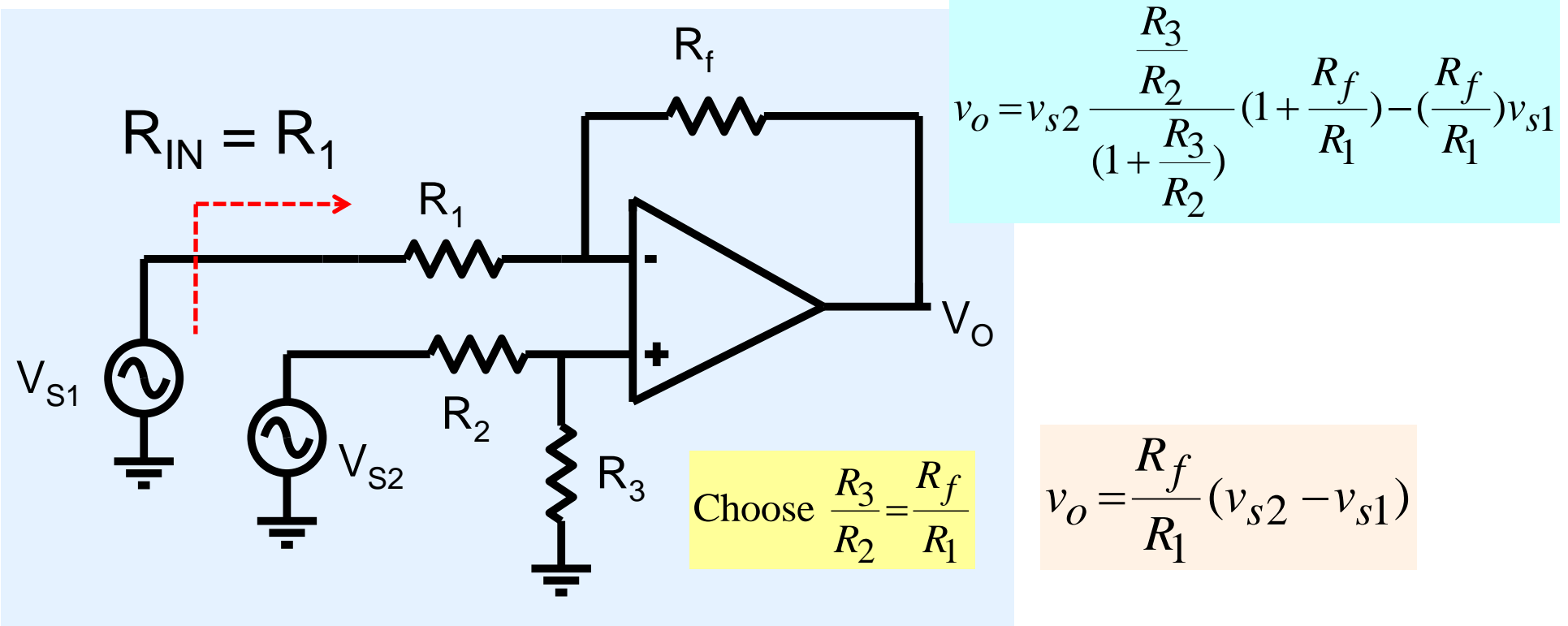


# Example



**$\sim -12V$**

# Difference Amplifier



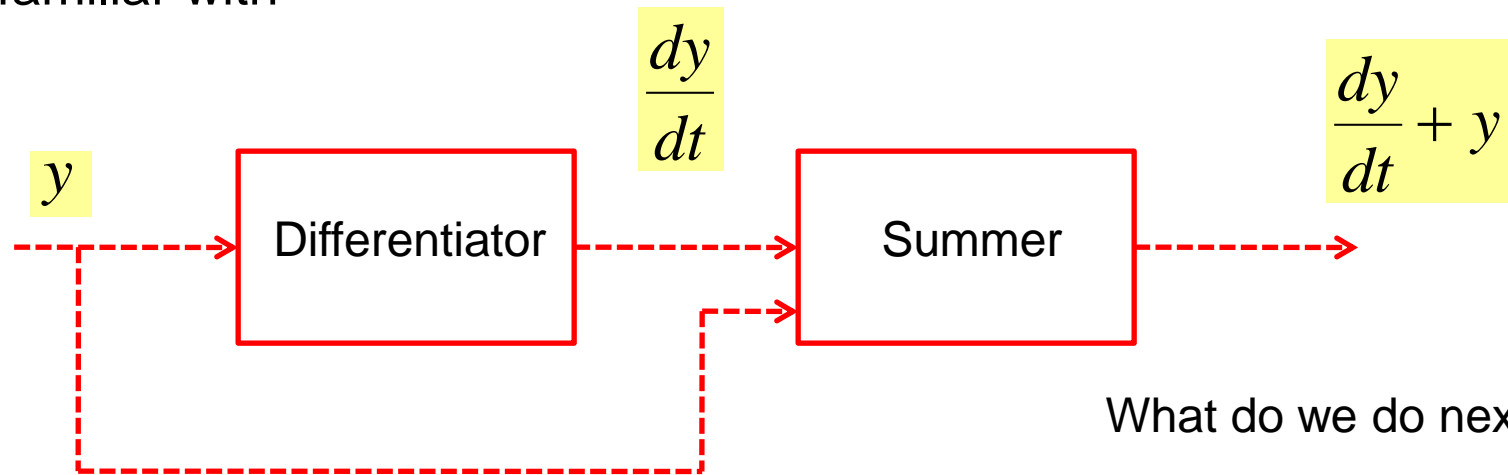
A drawback is that input resistance is relatively Lower

To change gain, we have to change two resistors and a slight mismatch can drastically reduce common mode rejection ratio

# Solving Differential Equations?

$$\frac{dy}{dt} + y = f(t)$$

Let us try and solve this equation using opamp circuit blocks that we are familiar with

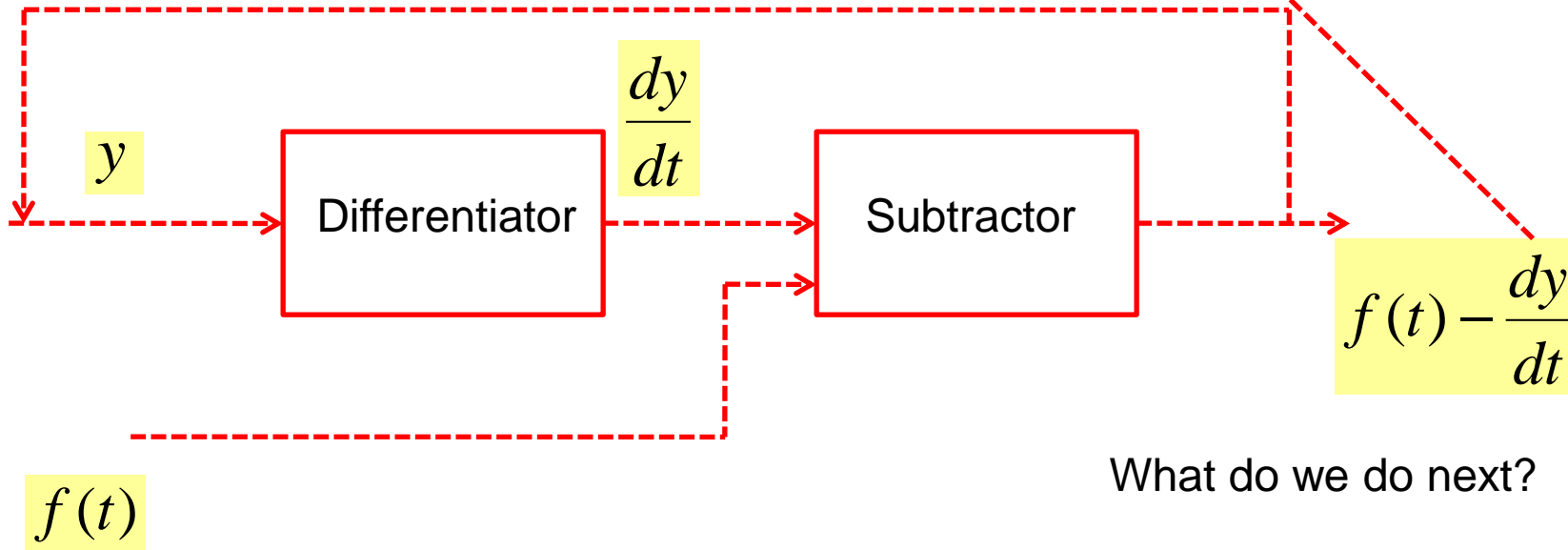


Where do we get  $y$  from?

# Solving Differential Equations?

$$\frac{dy}{dt} + y = f(t)$$

$$y = f(t) - \frac{dy}{dt}$$



## What do we do next?

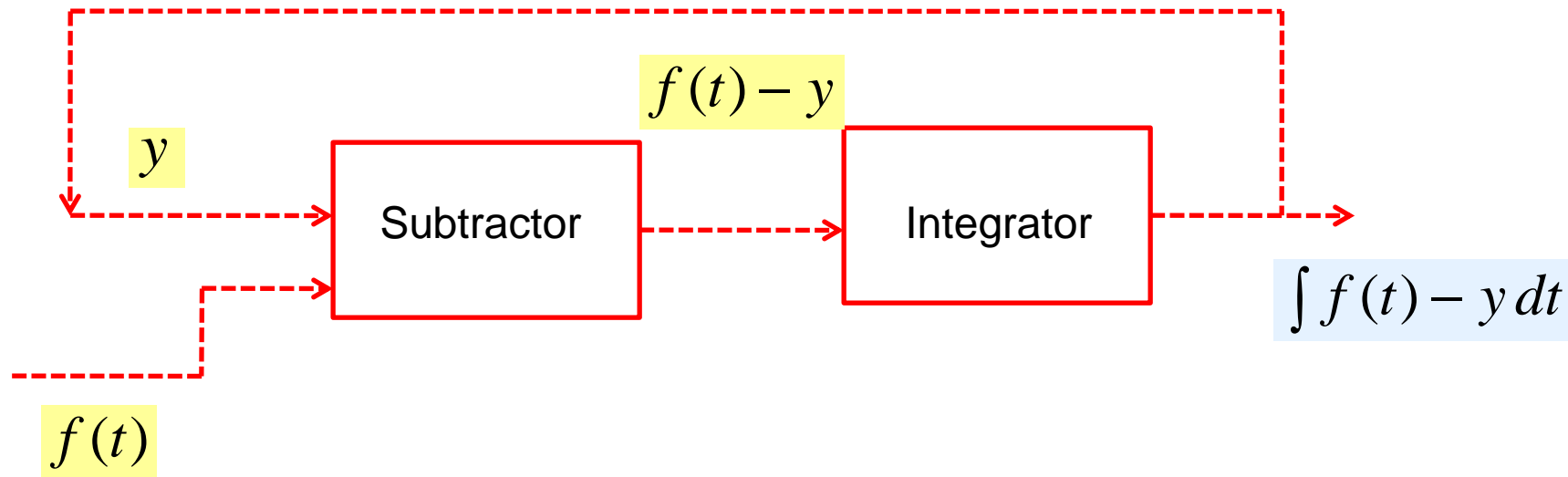
## Where do we get $y$ from?

Integrators are preferred over Differentiators because they are less sensitive to noise

$$\frac{dy}{dt} + y = f(t)$$

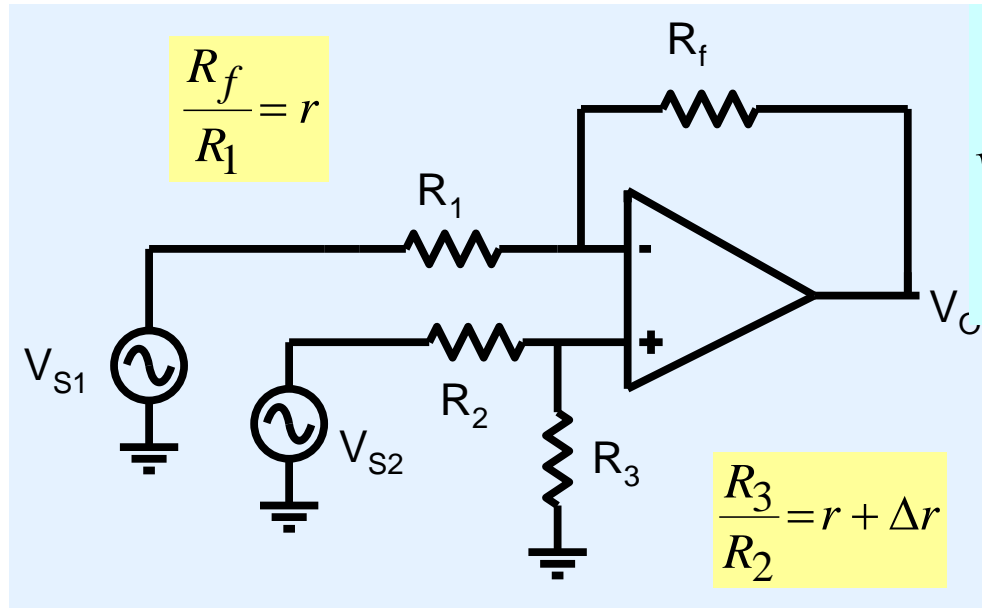
$$\frac{dy}{dt} = f(t) - y \Rightarrow$$

$$y = \int f(t) - y dt$$





# Effect Of Mismatches



$$v_o = v_{s2} \frac{\frac{R_3}{R_2}}{(1 + \frac{R_3}{R_2})} (1 + \frac{R_f}{R_1}) - (\frac{R_f}{R_1}) v_{s1}$$

$$v_o \cong (v_{s2} - v_{s1})r + v_{s2} \frac{\Delta r}{1 + r}$$

Error term

$$v_{id} = v_{s2} - v_{s1}$$

$$v_{ic} = \frac{v_{s1} + v_{s2}}{2}$$

$$v_{s2} = 0.5v_{id} + v_{ic}$$

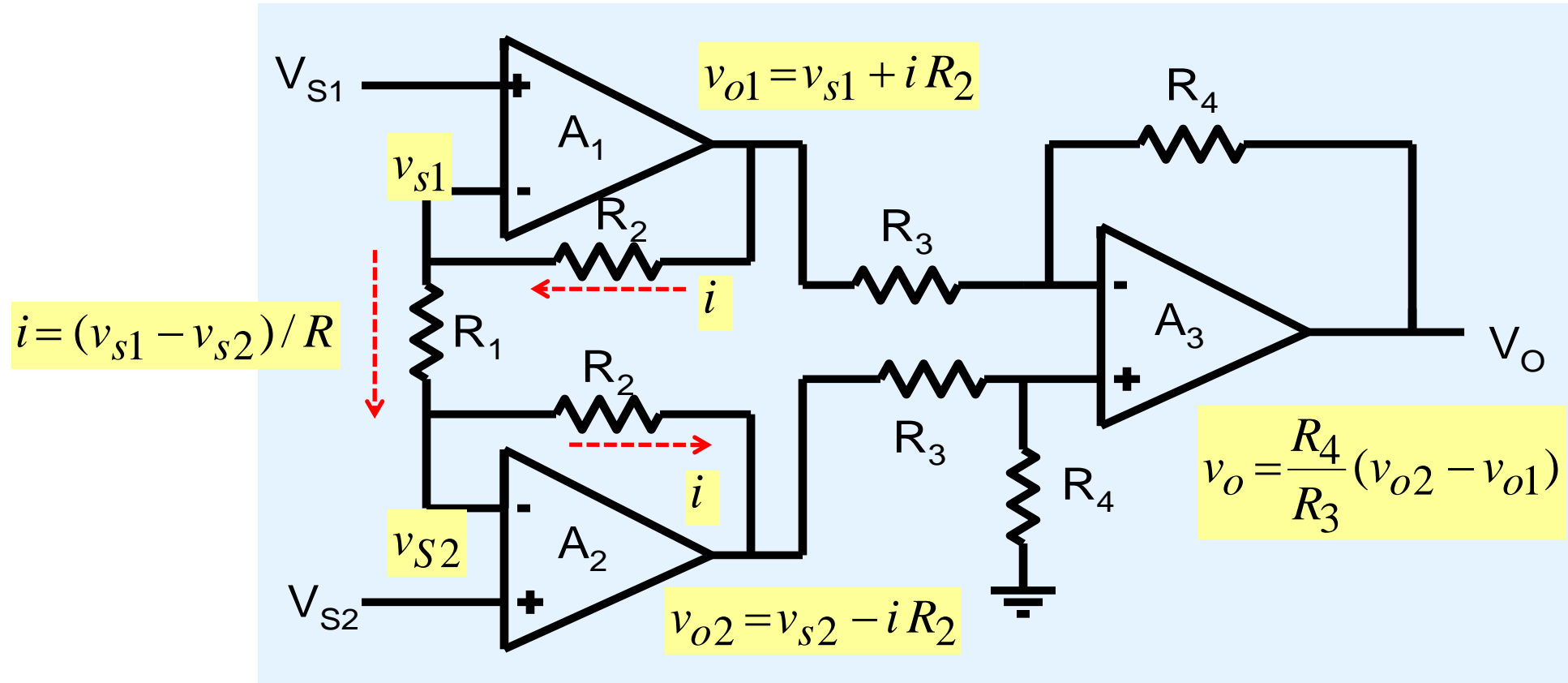
$$v_o = A_d v_{id} + A_{cm} v_{ic}$$

$$A_{dm} = r$$

$$A_{cm} = \frac{\Delta r}{1 + r}$$

Common mode gain and CMRR depend on mismatches

# Instrumentation Amplifier



$$v_o = \frac{R_4}{R_3} \times \left(1 + \frac{2R_2}{R_1}\right) \times (v_{s2} - v_{s1})$$

Very high input Resistance

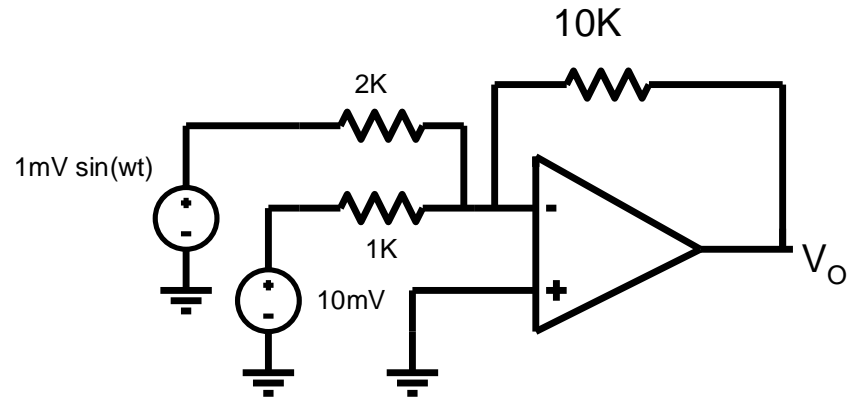
Can change one resistor  $R_1$  and change gain

# **ESC102 : Introduction to Electronics**

## **HW10: Solution**

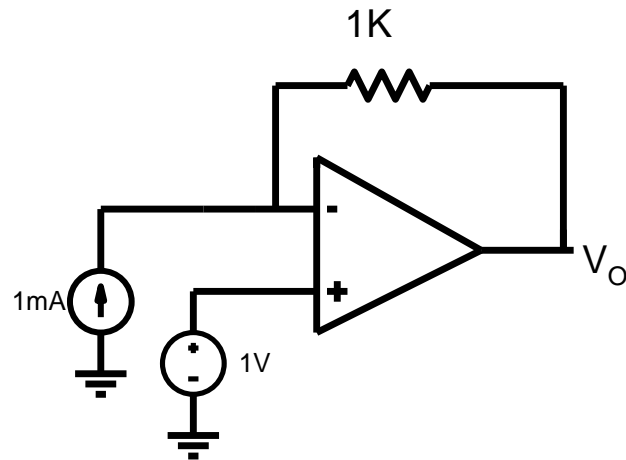
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Q.1 Determine the output of the ideal opamp circuits shown below



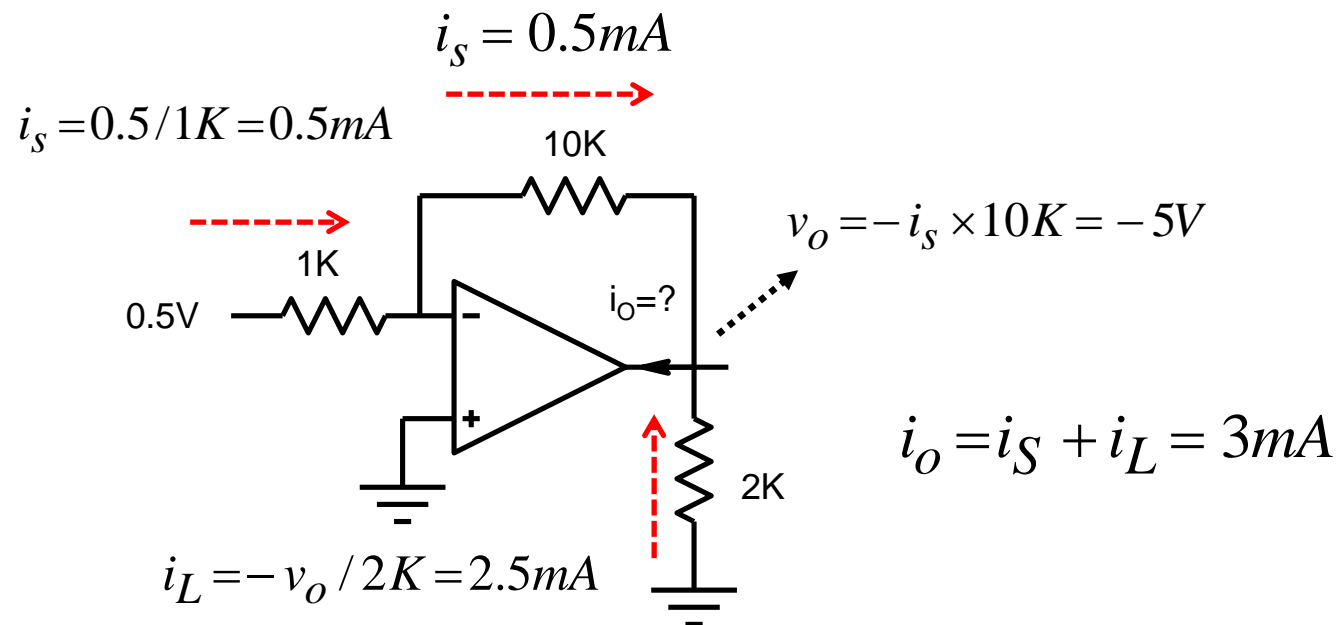
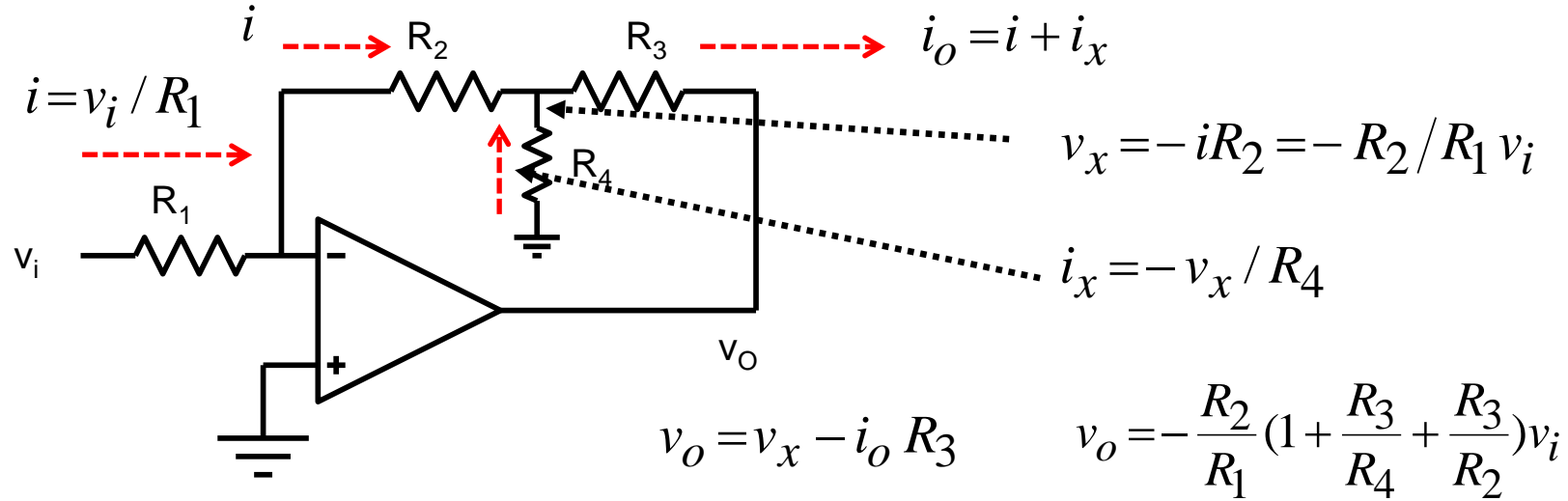
$$v_o = -\left\{ \frac{10K}{1K} \times 10mV + \frac{10K}{2K} \times 1mV \sin(\omega t) \right\}$$

$$= -\{0.1 + 5 \times 10^{-3} \sin(\omega t)\}$$



$$v_+ = v_- = 1V$$

$$\frac{1 - v_o}{1K} = 1mA \quad v_o = 0V$$



$$V_O = 2v_{s1} + 4v_{s2} - 8v_{s3} - 10v_{s4}$$

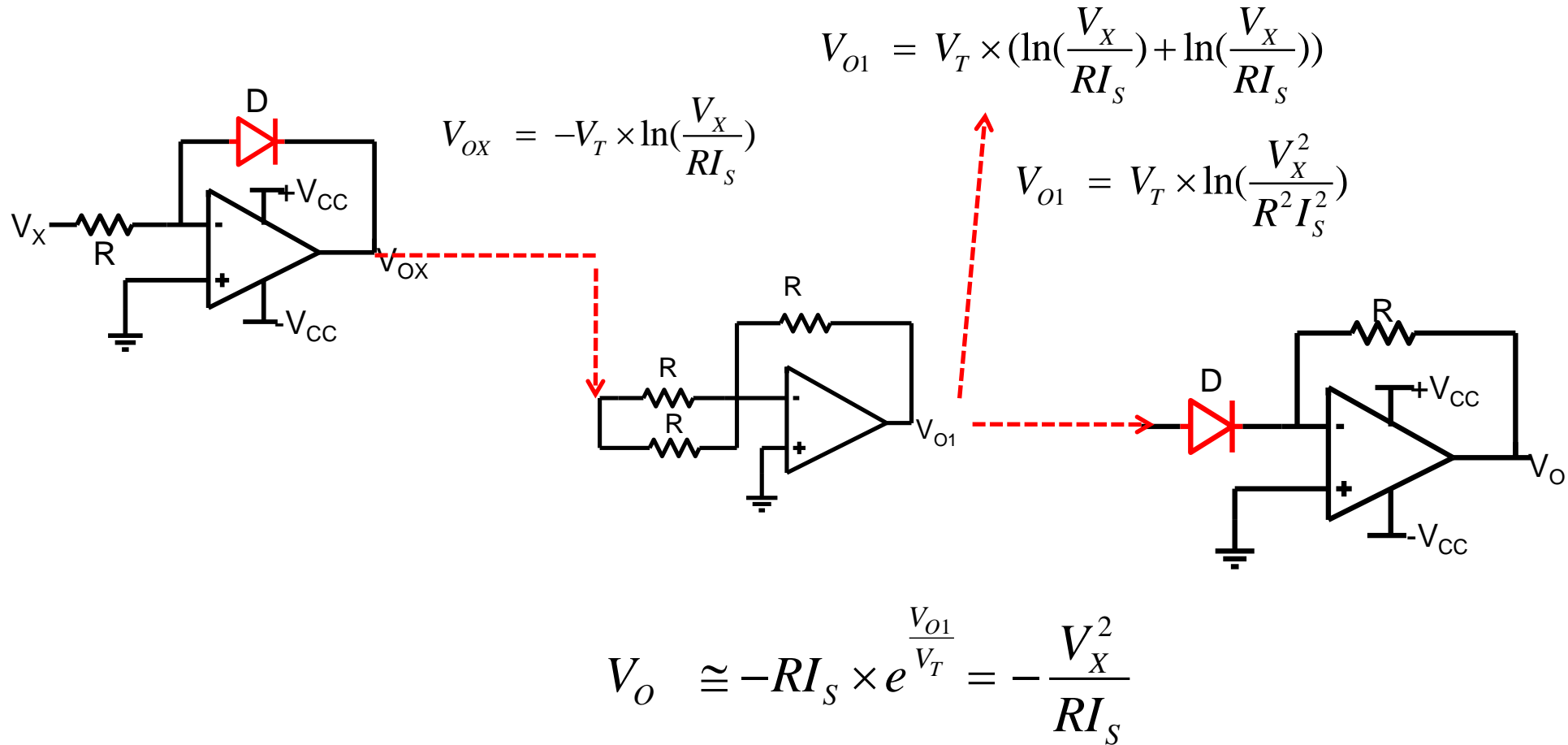

$$v_o = -\left(\frac{R_f}{R_3}\right)v_{s3} - \left(\frac{R_f}{R_4}\right)v_{s4} + \left(1 + \frac{R_f}{R_3 \parallel R_4}\right) \times \frac{R_P}{R_1} v_{s1} + \left(1 + \frac{R_f}{R_3 \parallel R_4}\right) \times \frac{R_P}{R_2} v_{s2}$$

Choose :  $R_f = 10K \Rightarrow R_3 = 1.25K \Rightarrow R_4 = 1K$

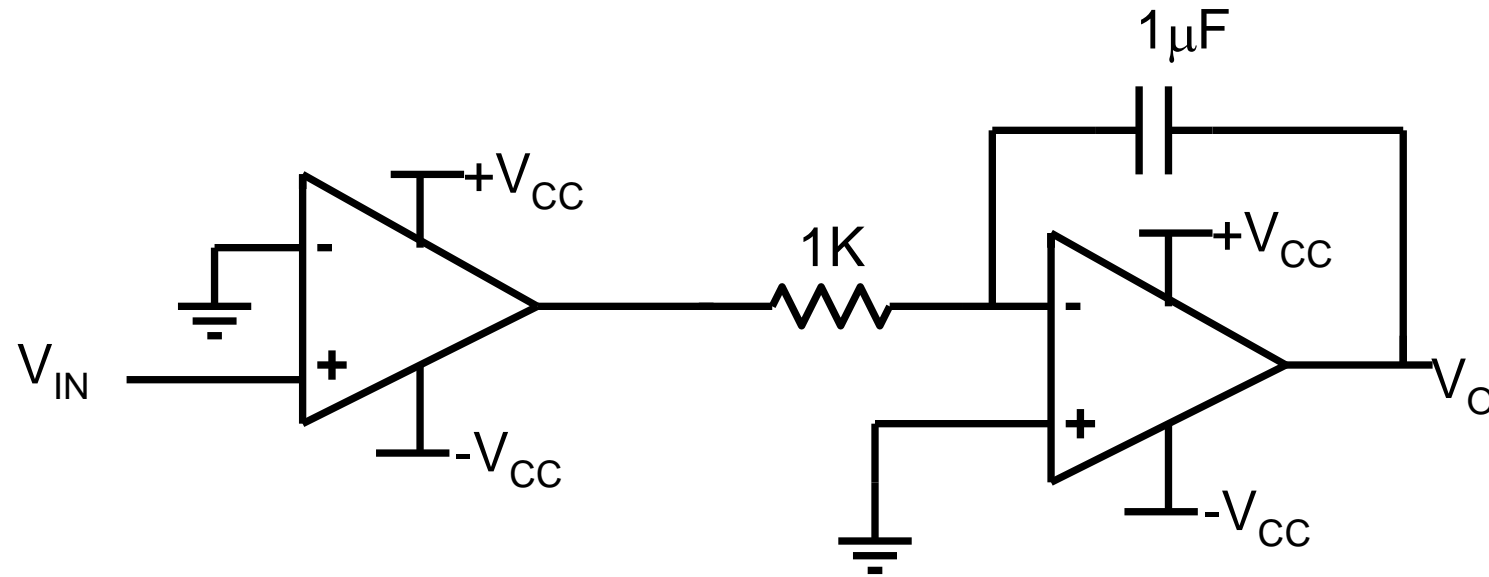
$$\Rightarrow \frac{R_P}{R_1} = 0.105 \quad \Rightarrow \frac{R_P}{R_2} = 0.211 \quad \Rightarrow \frac{R_1}{R_2} = 2$$

Choose :  $R_2 = 1K \Rightarrow R_1 = 2K \Rightarrow R_P = 0.211K \Rightarrow R_5 = 0.308K$

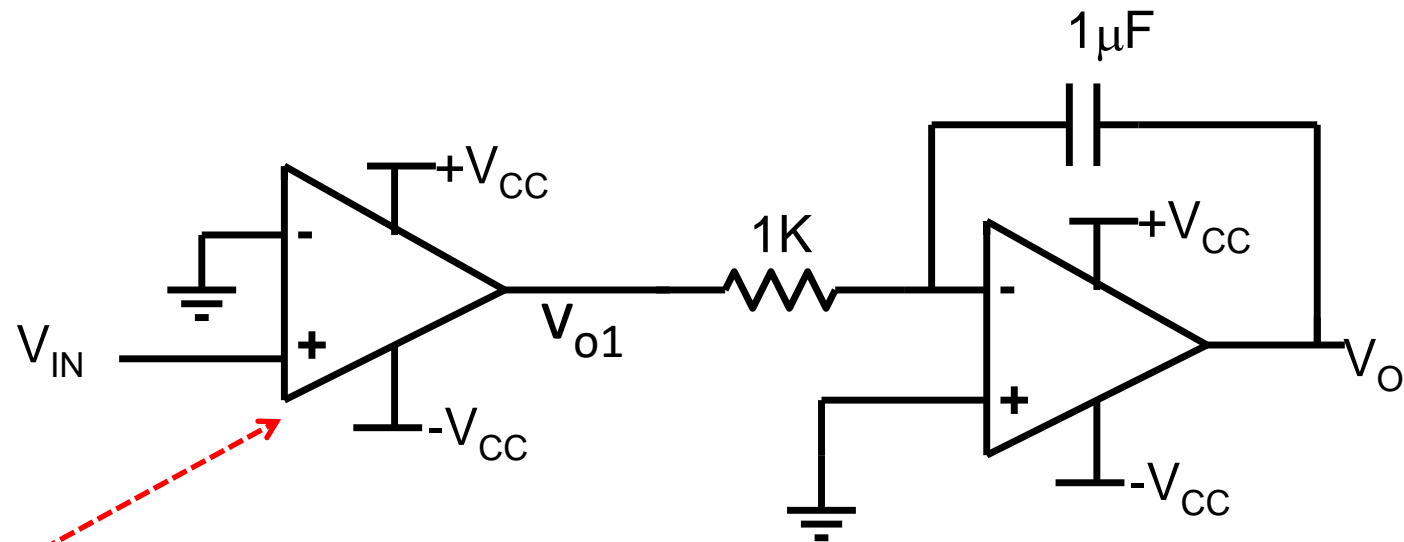
Q.3 Design an opamp circuit that can produce  $V_O = K \times V_{IN}^2$  where  $V_{in}$  is the input voltage.



Q.4 Sketch the output voltage of the circuit shown below for  $V_{in} = 1V \sin(2\pi ft)$ ;  $f = 1KHz$  and supply voltages of  $\pm 5V$



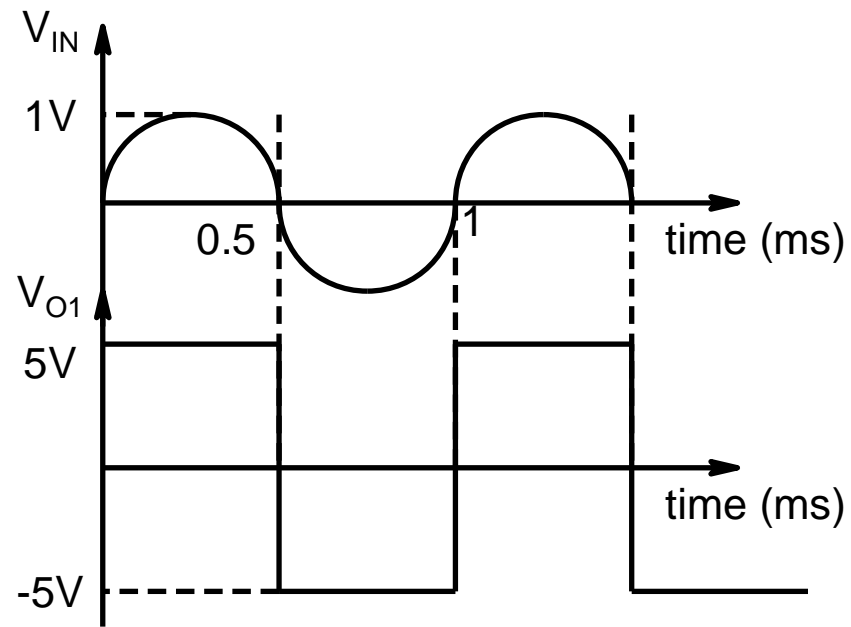


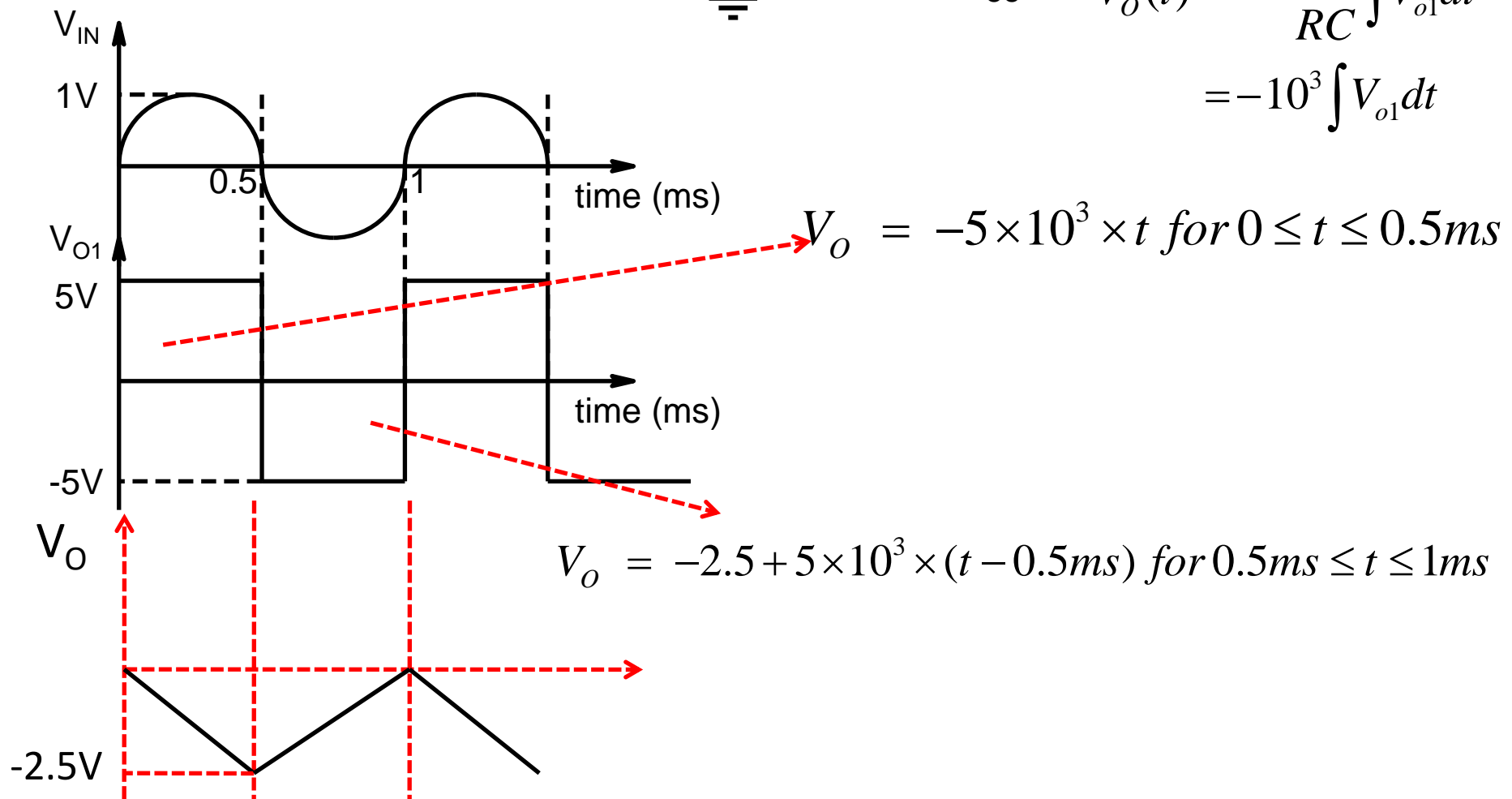
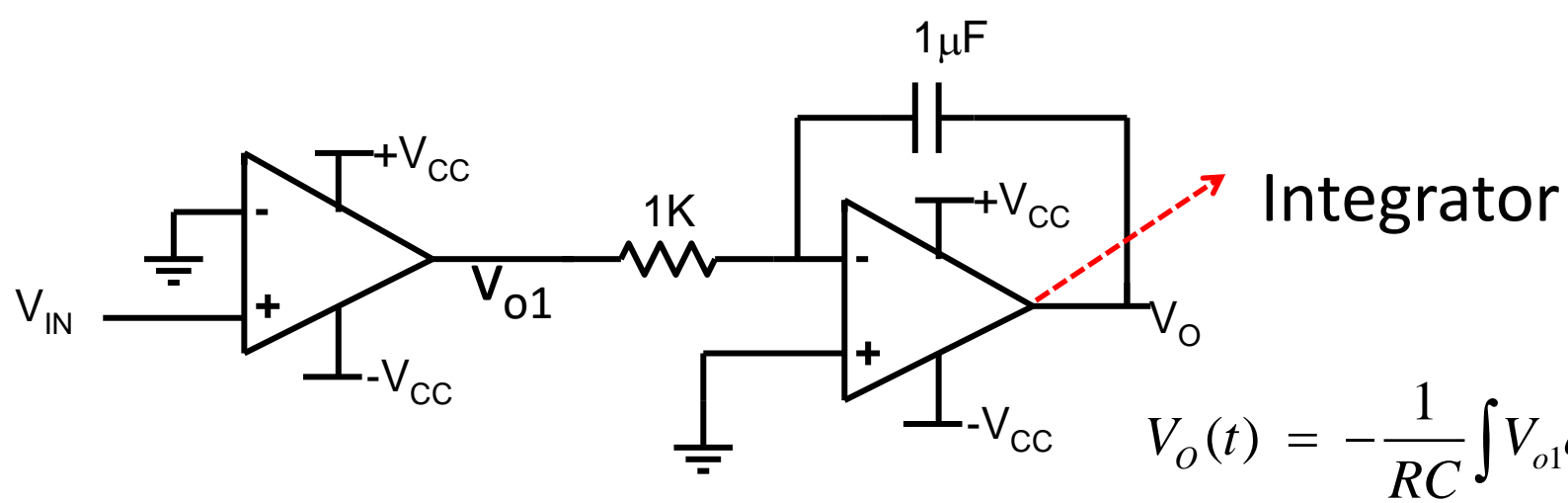


comparator

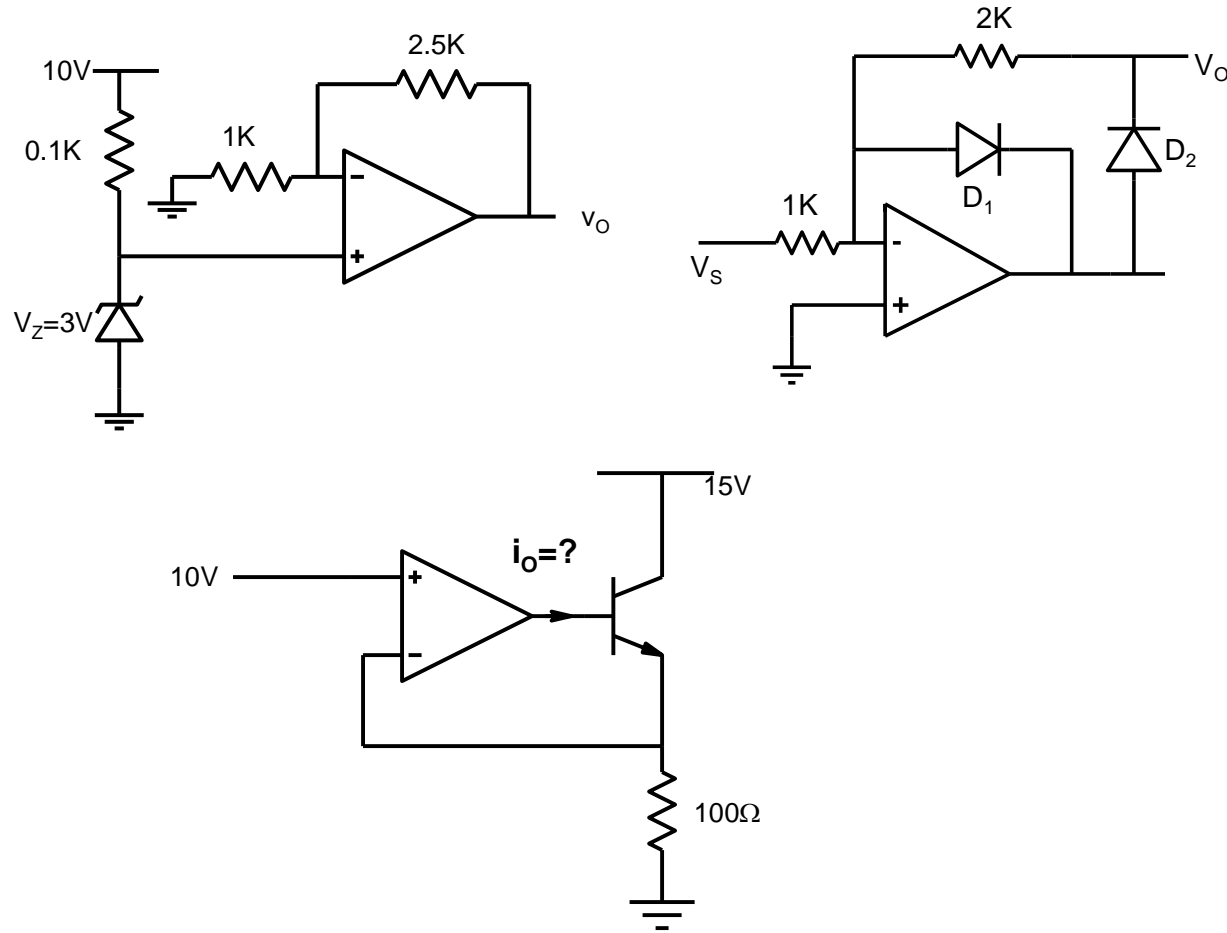
$$V_{O1} = +5V \text{ if } v_{in} > 0$$

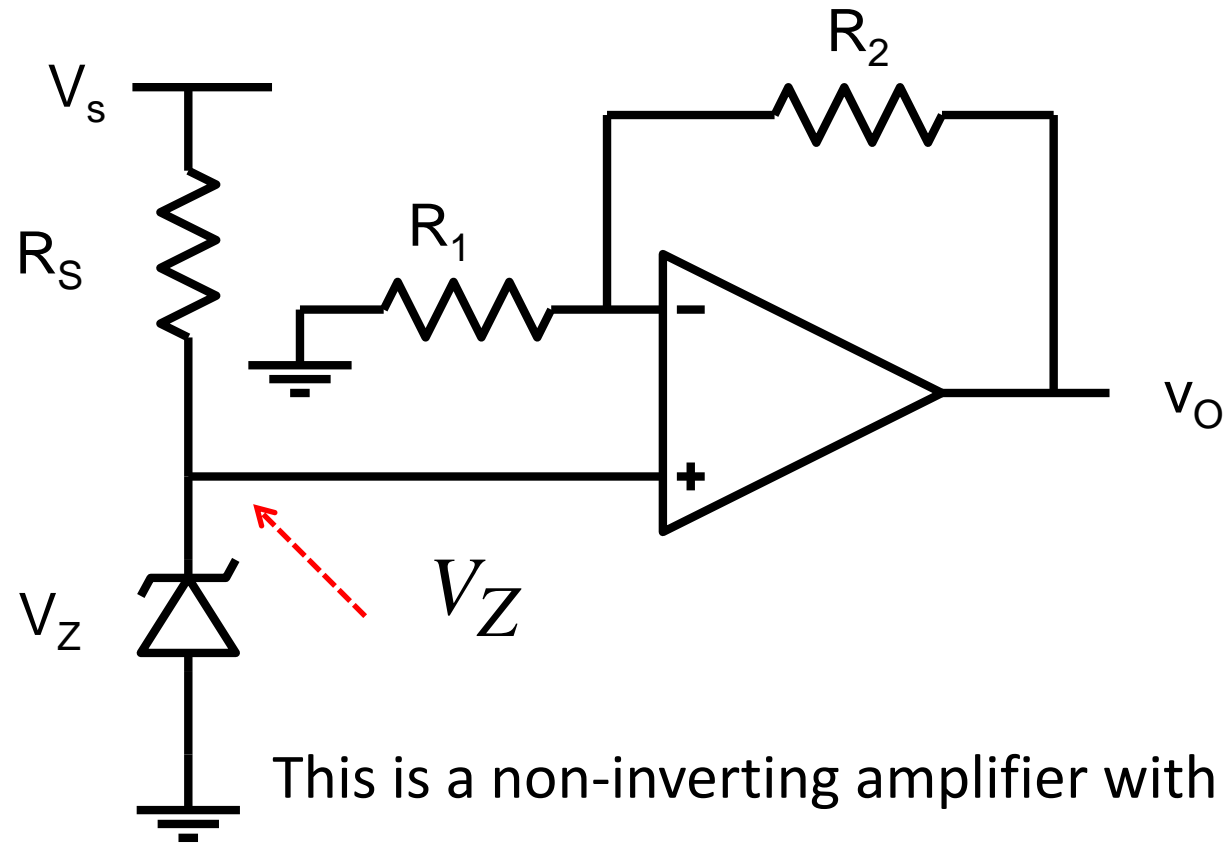
$$= -5V \text{ if } v_{in} < 0$$





Q.5 Determine the output for the ideal opamp circuits shown below. For the circuit on the right assume that diodes have cut-in voltage of 0.7V. Analyze the circuit for  $V_s = 1V$  and  $V_s = -1V$ . For the transistor assume a current gain of 100. What is the usefulness of each of the circuits?

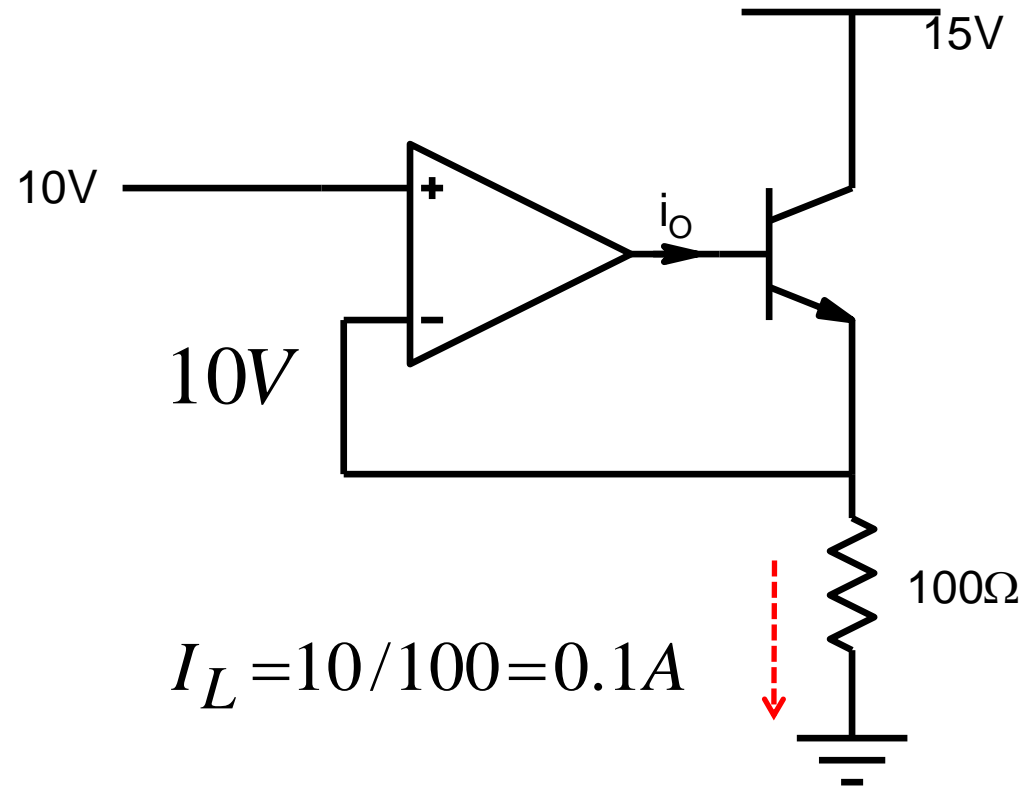




This is a non-inverting amplifier with  $V_Z$  as input

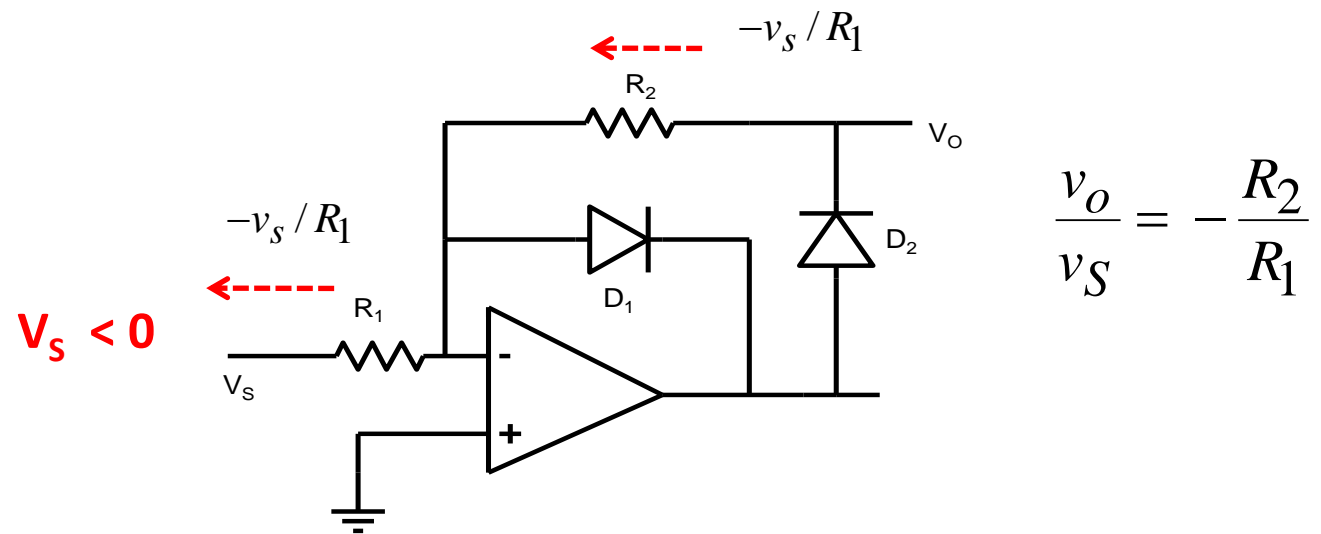
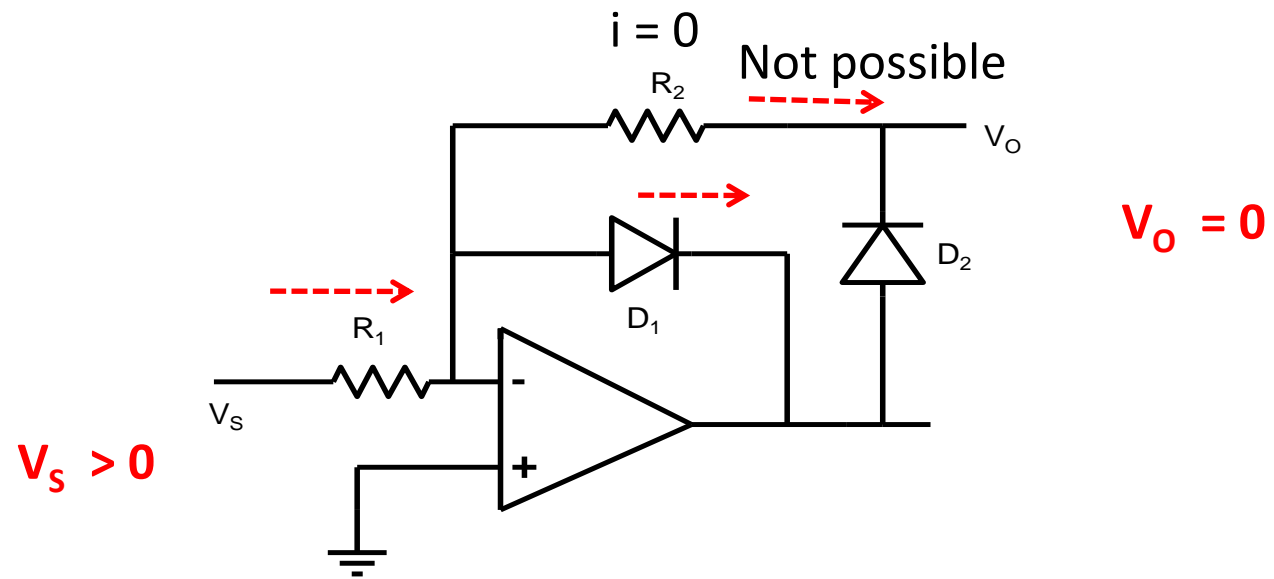
$$v_o = V_Z \left( 1 + \frac{R_2}{R_1} \right)$$

The circuit produces a constant output voltage  $V_o$  even though supply voltage may vary and thus acts like a voltage regulator.



$$I_o = I_B = \frac{I_E}{\beta + 1} = 0.99mA$$

The circuit can supply load current that is much larger than opamp output current



The circuit acts like a rectifier